



AARHUS UNIVERSITET

Smertefri kirurger

Udvikling, lancering og evaluering af strategier til forebyggelse af muskelskeletbesvær blandt abdominal- og bækkenkirurger



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01 Forord

Denne rapport præsenterer hovedresultaterne fra forskningsprojektet Smertefri kirurger, der er gennemført som et PhD-projekt ved Aarhus Universitet, Institut for Klinisk Medicin. Projektet har haft til formål at skabe ny, praksisnær viden om muskelskeletbesvær blandt kirurger og at udvikle, lancere og afprøve konkrete strategier, der kan forebygge og reducere dette besvær blandt abdominal- og bækkenkirurger, det vil sige kirurger inden for gynækologi, urologi og mave-tarm kirurgi.

Rapporten er målrettet sundhedsvæsenet, arbejdsmiljøansvarlige, ledere, uddannelsesansvarlige og fagprofessionelle indenfor kirurgi. Rapporten er udarbejdet på grundlag af PhD-afhandlingen *Pain-Free Surgeons*.

Projektet er bygget op om to studier. Det første er et systematisk litteraturstudie, der kortlægger den eksisterende viden om ergonomiske tiltag i operationsstuen. Det andet er et todelt interventionsstudie, hvor der først blev udviklet og lanceret et sæt ergonomiske anbefalinger på ni danske kirurgiske afdelinger, og hvor effekten af at supplere disse anbefalinger med individuelt tilpasset fysisk træning derefter blev testet i et randomiseret, kontrolleret forsøg. Rapporten giver et samlet overblik over resultaterne, mens PhD-afhandlingen (vedlagt som Appendix) indeholder detaljerede metodiske beskrivelser, analyser og fulde datagrundlag.

Projektet er gennemført i tæt samarbejde med de deltagende kirurgiske afdelinger på danske regions- og universitetshospitaler samt med internationale forskningspartnere ved Mayo Clinic og University of Michigan i USA, der har bidraget med ekspertise inden for kirurgisk ergonomi. Vi takker alle deltagende afdelinger, kirurger og operationssygeplejersker for deres engagement, og vi takker Arbejdsmiljøforskningsfonden for den økonomiske støtte, der har gjort projektet muligt.

Der er undervejs anvendt AI som redskab til oversættelse, sammenskrivning og sproglig bearbejdning, mens alle resultater, vurderinger og konklusioner er forfatterens egne.

02 Indledning

02.01 Baggrund for problemstilling

Muskelskeletbesvær som arbejdsbetinget sundhedsproblem

Muskelskeletbesvær er en samlebetegnelse for smerter og gener i kroppens bevægeapparat. Når generne primært skyldes eller forværres af arbejdet og det miljø, arbejdet udføres i, taler man om arbejdsbetingede muskel- og skeletbesvær (1). I EU rapporterer omkring 60 % af arbejdstagerne muskelskeletbesvær, hvor ryggen og de øvre ekstremiteter er blandt de hyppigst ramte kropsregioner (1). Ansatte i sundhedssektoren har en højere forekomst end den gennemsnitlige europæiske arbejdstager (2), og kirurger udgør en undergruppe med særligt høj forekomst. Selvom kirurgi primært opfattes som et vidensintensivt fag, placerer de fysiske krav i arbejdet kirurger blandt de erhvervsgrupper, der har lige så høj forekomst af muskelskeletsmerter som mere traditionelt fysisk belastende fag (3).

Kirurger er højt specialiserede fagpersoner, hvis uddannelse tager mange år. Med et stigende pres på sundhedsvæsenet, hvor flere patienter forventes at skulle opereres samtidig med en forudsigelse om mangel på kirurger allerede fra 2030, er kirurgers arbejdsevne ikke alene vigtig for den enkelte, men også for sundhedsvæsenets samlede behandlingskapacitet (4).

Forekomst og konsekvenser blandt kirurger

På tværs af kirurgiske specialer er muskelskeletsmerter udbredte. En metaanalyse har rapporteret 12-måneders-forekomster på 60 % for nakkesmerter, 52 % for skuldre og 49 % for ryg (3), mens et andet studie dokumenterer en forekomst på 68 % på tværs af blandede kirurgiske specialer (5). Besværet er ikke begrænset til ét kirurgisk felt, men udgør et bredt arbejdsmiljøproblem i kirurgien. De hyppigst ramte kropsregioner er nakke, skuldre og ryg, og smerterne optræder ofte i flere regioner samtidig (6, 7).

Den høje forekomst har konsekvenser på flere niveauer. På individniveau påvirker smerterne kirurgernes generelle trivsel; en undersøgelse blandt danske abdominal- og bækkenkirurger viste, at muskelskeletsmerter går ud over både arbejde, fritidsaktiviteter og søvn (6), og smerter er forbundet med øget risiko for udbrændthed (8, 9). På professionsniveau kan smerterne true arbejdsevnen og karrierelængden; blandt kirurger med muskelskeletsmerter anslås det, at omkring 12 % får behov for orlov, må begrænse eller ændre deres praksis eller trække sig tilbage tidligt (3). Forekomsten af smerter i flere regioner samtidig er særligt forbundet med nedsat arbejdsevne blandt sundhedspersonale (10).

På klinisk og organisatorisk niveau har smerterne betydning for det kirurgiske arbejde og kvaliteten af behandlingen, idet kirurger oplever smerte og træthed som præstationsbegrænsende under operationer (8, 11). Indirekte kan kirurgers smerter også reducere den samlede operationskapacitet, når kirurger nedsætter deres operationsmængde for at håndtere smerterne eller er fraværende på grund af sygdom (12, 13). Muskelskeletsmerter blandt kirurger bør derfor ikke alene forstås som et individuelt helbredsproblem, men også som et fagligt og organisatorisk anliggende.

Fysiske krav i det kirurgiske arbejde

Kirurgisk arbejde indebærer specifikke fysiske krav, der kan øge risikoen for muskelskeletsmerter: langvarige statiske arbejdsstillinger, akavede positioner, gentagne bevægelser, høje præcisionskrav og begrænset mulighed for muskulær hvile under indgreb (2, 14). Disse krav er belastende, fordi de ofte indebærer en lav, men vedvarende muskelaktivitet over lange perioder (15). I modsætning til dynamisk arbejde giver statisk belastning kun lidt variation og få muligheder for restitution, hvilket kan føre til lokal udtrætning og over tid til smerter (16, 17). Selv når de absolutte kraftkrav er lave, kan den relative og kumulative belastning derfor være betydelig.

De fysiske krav varierer med den kirurgiske modalitet, fordi hver tilgang stiller sine egne ergonomiske krav. Ved åben kirurgi har kirurgen direkte indblik i operationsfeltet, men arbejdet indebærer ofte langvarig stående stilling og foroverbøjet nakke, hvilket kan forstærkes af brug af lupbriller. Laparoskopi (kikkertkirurgi) stiller krav i form af reduceret føling og taktil feedback, todimensionel visualisering og instrumenthåndtering gennem faste indstikssteder. Ved robotassisteret kirurgi sidder kirurgen ved en konsol, hvilket kan mindske belastningen i forhold til stående arbejde, men kan introducere andre belastende stillinger som løftede skuldre, statisk belastning af lænden og høj muskelaktivitet i underarmene (18). Ingen modalitet er beskyttende; modaliteterne flytter snarere belastningen mellem kropsregioner, end de fjerner den (19, 20).

Også varigheden og kompleksiteten af arbejdet har betydning. En højere operationsmængde (21) og længere indgreb (22) er forbundet med muskelskelet smerter, og operationer på patienter med højere kropsvægt er forbundet med mere belastende arbejdsstillinger (23), sandsynligvis fordi de forlænger den tid, kirurgen tilbringer i fastlåste arbejdsstillinger, og øger den fysiske belastning. Både dårlige arbejdsstillinger og megen tid i højrisikostillinger er forbundet med smerter (24). Abdominal- og bækkenkirurger i gynækologi, urologi og mave-tarm kirurgi deler flere af de samme modaliteter og står derfor over for sammenlignelige ergonomiske udfordringer, hvilket er grunden til, at projektet fokuserer på netop disse specialer.

Balancen mellem krav og kapacitet

De samme ydre krav opleves forskelligt afhængigt af kirurgens fysiske kapacitet, restitution og individuelle karakteristika. Nogle af disse er ikke-modificerbare, herunder genetik, køn, alder og til dels kropsbygning, mens andre, som kondition og muskelstyrke kan ændres. Inden for den fysiske dimension kan kirurgers muskelskelet smerter forstås som et muligt misforhold mellem de ydre arbejdskrav og kirurgens individuelle fysiske kapacitet. Når kravene ligger inden for kapaciteten, er risikoen for smerter lav og omvendt hvis kravene overstiger kapaciteten, bliver den relative belastning for høj, og

kirurgen er i øget risiko for muskulær udtrætning, smerter, nedsat funktion og over tid kroniske gener (25). Med alderen falder den fysiske kapacitet, mens arbejdskravene ofte forbliver de samme. Det kan blive kritisk, når kravene overstiger kapaciteten. Heraf følger to komplementære strategier: at reducere arbejdskravene gennem ergonomi (at tilpasse operationsstuen til kirurgen) og at øge den fysiske kapacitet gennem målrettet træning (at tilpasse kirurgen til operationsstuen). Disse to strategier udgør projektets to interventionsspor.

At tilpasse operationsstuen til kirurgen: ergonomi

Ergonomi er disciplinen, der handler om at indrette arbejdet, så det passer til mennesket og dermed forbedrer komfort, sikkerhed og præstation. Den fysiske ergonomi i operationsstuen adresserer risikofaktorer som akavede arbejdsstillinger, gentagne bevægelser, vridninger og foroverbøjning (26) og kan i praksis omfatte justering af skærmlacering og bordhøjde, kirurgens egen positionering, instrumenthåndtering samt indlæggelse af korte muskulære pauser (14, 27).

På trods af ergonomiens relevans rapporterer kirurger kun begrænset opmærksomhed og formel oplæring, samt fortæller at ergonomi sjældent indgår i speciallægeuddannelsen (28). Det er væsentligt, fordi kirurger ofte opfatter deres arbejdsstillinger som en årsag til smerter (29). Uden tilstrækkelig ergonomisk viden mangler de redskaberne til at genkende og ændre uhensigtsmæssige belastningsmønstre, før symptomer opstår. Højere ergonomisk bevidsthed er forbundet med hyppigere ergonomisk praksis (30). Selvom ergonomi i stigende grad anbefales som strategi mod muskelskeletmerter, var det før projektets start uklart, hvilke specifikke ergonomiske tiltag der reelt var afprøvet i operationsstuen, og om de kunne forbedre kirurgers muskelskelethelbred (3, 20).

At tilpasse kirurgen til operationsstuen: fysisk træning

Fysisk aktivitet kan paradoksalt nok være både en del af problemet og en del af løsningen (16). Arbejdsrelateret fysisk aktivitet indebærer ofte langvarig statisk belastning, akavede

stillinger og tilstrækkelig restitution, og selvom den er trættende, er intensiteten ikke tilstrækkelig til at skabe en gavnlig fysiologisk tilpasning (17). Fysisk træning i fritiden er derimod kortvarig, struktureret, progressiv og af højere intensitet, hvilket er nødvendigt for at forbedre muskelstyrke, udholdenhed og kondition. For at træning skal have en sundhedsfremmende og smertelindrende effekt, bør den være tilstrækkelig intensiv, specifik for de relevante kropsregioner, tilpasset den enkeltes kapacitet og fulgt op af tilstrækkelig restitution (31).

Den anden strategi mod muskelskeletsmarter er derfor at øge kirurgens fysiske kapacitet og dermed evnen til at 'tåle' arbejdets krav ved at sænke den relative belastning. Selvom fysisk træning er veletableret inden for idrætsvidenskab, rehabilitering og arbejdsmiljø (25), har den først for nyligt fået opmærksomhed som strategi til at fastholde kirurgers muskelskelethelbred (32).

En tilgang, der operationaliserer ovenstående, er Intelligent Motion (IPET efter engelsk titel: Intelligent Physical Exercise Training). IPET er en evidensbaseret metode for den arbejdende befolkning, der retter sig mod kapacitetssiden af balancen mellem krav og kapacitet (33). Konceptet består af 50 minutters ugentlig træning, der for den enkelte skræddersyes som en kombination af konditions-, styrke-, funktionel og balancetræning. IPET er undersøgt i mere end 20 randomiserede forsøg med over 4.000 arbejdstagere, primært i Danmark, og har på tværs af faggrupper vist gavnlige effekter på muskelskeletsmarter, styrke, kondition og arbejdsrelateret helbred (25, 34). Effekten hænger dog sammen med træningsmængden, og der er en stærk dosis-respons-sammenhæng (35). Forud for projektet, var det dog endnu ikke afklaret, om IPET er anvendelig og effektiv blandt kirurger, hvis arbejde er organiseret omkring operationsprogrammer, akutte opgaver og begrænset kontrol over dagligdagen.

02.02 Formål

Det overordnede formål med projektet var at udvikle, lancere og evaluere strategier til at forebygge og reducere muskelskelet smerter blandt abdominal- og bækkenkirurger. Dette skete ud fra en trinvis tilgang fra evidenssyntese over interventionsudvikling og - lancering til effekttest (36). Formålet blev operationaliseret gennem tre mål:

1. **Mål 1:** At gennemføre et systematisk litteraturstudie af ergonomiske interventioner anvendt i operationsstuen og deres effekt på abdominal- og bækkenkirurgers muskelskelethelbred (Studie 1).
2. **Mål 2:** At omsætte litteraturstudiets fund til evidensbaserede, gennemførlige ergonomiske anbefalinger (God Ergonomi), og lancere disse på danske kirurgiske afdelinger og at vurdere kirurgernes kendskab til og praktisering af anbefalingerne (Studie 2, fase 1).
3. **Mål 3:** At undersøge den yderligere effekt af IPET i tillæg til God Ergonomi sammenlignet med God Ergonomi alene i et randomiseret, kontrolleret forsøg (Studie 2, fase 2).

03 Metoder

03.01 Studiepopulation og overordnede rammer

Projektets målgruppe var abdominal- og bækkenkirurger, herunder mave-tarm kirurger, urologer, gynækologer og almene kirurger, afhængigt af den lokale organisering. Denne population blev valgt, fordi deres kirurgiske modaliteter, arbejdsforhold og arbejdsstillinger i vid udstrækning er sammenlignelige, så ergonomiske anbefalinger forventeligt ville overlappe på tværs af specialerne (6). Projektet omfattede de tre væsentligste modaliteter: åben kirurgi, laparoskopi og robotassisteret kirurgi.

Projektet var bygget op som to metodisk sammenhængende studier. Studie 1 var et systematisk litteraturstudie, der skabte det evidensbaserede fundament. Studie 2 var et

totelt interventionsstudie: fase 1 udviklede og lancerede de ergonomiske anbefalinger (God Ergonomi) og vurderede deres udbredelse, og fase 2 var et randomiseret, kontrolleret forsøg, der testede effekten af at tilføje fysisk træning. Viden fra ét trin informerede designet af det næste. Projektet fulgte gældende etiske retningslinjer og databeskyttelsesregler, og deltagelse forudsatte informeret samtykke (36).

Internationalt samarbejde

Projektet blev udviklet gennem internationalt samarbejde med forskningsgruppen hos Professor Susan Hallbeck ved Mayo Clinic (USA) og Dr. Kristin Chrouser ved University of Michigan (USA), som begge har etableret ekspertise inden for kirurgisk ergonomi og interventioner (27, 37, 38). Samarbejdspartnerne bidrog til udformningen af både de ergonomiske anbefalinger og det randomiserede forsøg. Parallelt med studie 2 i Danmark blev der igangsat tilsvarende studie i USA, men de amerikanske data indgår ikke i denne afrapportering, da udrulningen i USA blev forsinket og alle data er derfor ikke indhentet.

03.02 Studie 1: Systematisk litteraturstudie

Studie 1 var et systematisk review af ergonomiske interventioner leveret i operationsstuen, hvor evidensen blev sammenfattet efter interventionstype og rapporteret effekt på muskelskelethelbred og fysisk belastning. Reviewet havde to formål: at identificere effektive ergonomiske interventioner blandt abdominal- og bækkenkirurger og at danne et evidensbaseret grundlag for udviklingen af God Ergonomi.

En central metodisk beslutning var at ekskludere evidens fra simulations- og træningsmiljøer, da kravene i ægte kirurgi adskiller sig væsentligt fra kontrollerede miljøer (39). Inklusionen var derfor begrænset til ergonomiske interventioner anvendt under operation. Ergonomisk uddannelse blev inkluderet som interventionstype, men kun hvor indholdet udtrykkeligt var tænkt til at blive anvendt af kirurgerne under

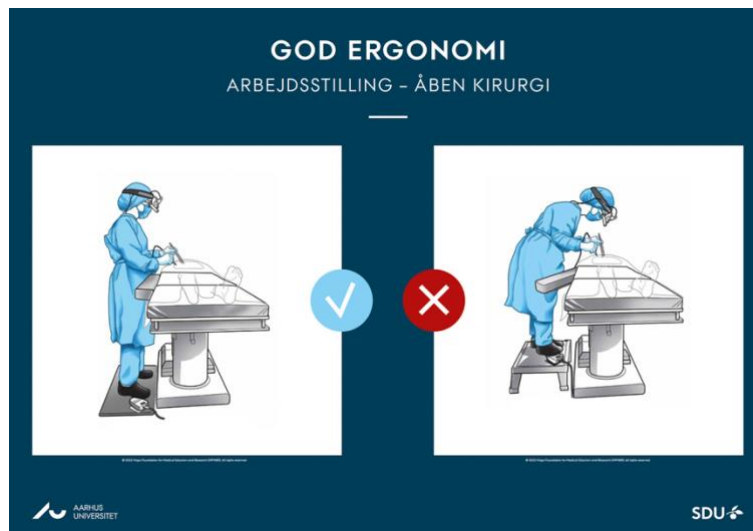
operation. Outcomes blev defineret bredt og omfattede både selvrapporterede, observatørbaserede og objektivt målte mål for muskelskelethelbred og fysisk belastning, da der var forventet stor variation i litteraturen. Studiedesign var egnede, hvis de indeholdt før og efter målinger.

Litteratursøgningen blev gennemført i tre databaser (Medline, Embase og Cochrane CENTRAL) fra databasernes start til juli 2022 med en opdatering i juli 2024. Søgningen kombinerede emneord og fritext om kirurgisk ergonomi og operationsstuer og blev udviklet med input fra en forskningsbibliotekar med speciale i arbejdsfysiologi. Screening, udvælgelse og dataudtræk blev håndteret i softwaren Covidence og gennemført uafhængigt af to bedømmere med en tredje til at afgøre uenigheder. Den metodologiske kvalitet blev vurderet med Downs & Black-tjeklisten, fordi den egner sig til både randomiserede og ikke-randomiserede studier (40); studier kunne klassificeres som fremragende, gode, rimelige eller ringe ud fra deres score. På grund af betydelig heterogenitet i studiedesign, outcomes og målemetoder blev fundene sammenfattet i en narrativ syntese, hvor studierne blev grupperet efter deres primære interventionskomponent. Alle studier blev medtaget uanset kvalitet for at give et bredt billede af den tilgængelige evidens.

03.03 Studie 2, fase 1: Udvikling og lancering af God Ergonomi

God Ergonomi (ERGO) bestod af to kernekomponenter, der blev udvalgt på baggrund af de interventionstyper, som viste de mest konsistente positive fund i Studie 1: (1) optimering af arbejdsstillinger i operationsstuen og (2) regelmæssige mikropausser. Tilsammen skulle de reducere de fysiske arbejdskrav og fremme variation i muskelaktiviteten under operation. Ergonomisk uddannelse blev leveret som et understøttende element gennem korte oplæg ved kirurgernes morgenmøder og korte informationsvideoer tilgængelige via QR-koder på plakater.

For at fremme bred anvendelse blev ERGO designet ud fra følgende principper: lette at tilgå uden store omkostninger og kunne anvendes i operationsstuen uden særligt udstyr eller lokal infrastruktur. Anbefalingerne for arbejdsstillinger blev illustreret på tre modalitetsspecifikke plakater (åben, laparoskopisk og robotassisteret kirurgi) med markering af anbefalede arbejdsstillinger samt placering af udstyr. Indholdet om mikropauser, øvelser udført stående i det sterile felt, blev tilpasset og oversat til dansk fra Mayo Clinics OR Stretch-værktøj med tilladelse og omsat til danske plakater og lydinstruktioner (27, 41). Hvor det var muligt, blev operationssygeplejersker inddraget for at understøtte en fælles opmærksomhed på ergonomi i operationsstuen, og kirurgerne blev opfordret til at melde deres hensigt om mikropauser ud ved gennemgang af operation. Se Appendix 1-3 i PhD afhandlingen. Nedenfor et par eksempler.



Udviklingen af ERGO i et adfærdsperspektiv tog afsæt i adfærdsforandringsmodellen the Behavior Change Wheel og den underliggende COM-B-model, der forstår adfærd som et

samspil mellem evne (Capability), mulighed (Opportunity) og motivation (Motivation) (42). ERGO understøttede evne gennem grundlæggende ergonomisk viden og praktisk vejledning, mulighed gennem plakater i operationsmiljøet og fælles opmærksomhed i teamet, og motivation gennem forklaring af, hvordan ERGO kan forebygge smerter.

ERGO blev lanceret på ni danske kirurgiske afdelinger. Forberedelsen krævede typisk koordinering over flere uger til måneder med afklaring af omfang, lokale ansvar og en kontaktperson på hver afdeling. Cirka 12 uger efter lanceringen blev der udsendt et ERGO spørgeskema (se Appendix 4 i PhD afhandlingen), der vurderede kirurgernes kendskab til de to ERGO komponenter og deres selvrapporterede praktisering af mikropausers og anbefalede arbejdsstillinger. Da der ikke fandtes et valideret, kirurg-specifikt spørgeskema for disse forhold, skal skemaet betragtes som eksplorativt. Udsendelse af ERGO skete i samarbejde med en kontaktperson, der udsendte link til alle relevante kirurger i afdelingen. Færdiggørelsen af fase 1 (ERGO spørgeskema) udgjorde samtidig adgangen til fase 2.

03.04 Studie 2, fase 2: Randomiseret, kontrolleret forsøg

Hvor fase 1 etablerede et ergonomisk fundament, var formålet med fase 2 at undersøge effekten af at tilføje IPET til ERGO i forhold til at reducere kirurgernes muskelskeletsmarter. Forsøget var et 20-ugers randomiseret, kontrolleret forsøg med to parallelle grupper. Deltagerne blev individuelt randomiseret i forholdet 1:1, stratificeret efter smertestatus (forekomst af muskelskeletsmarter på mindst 3 på en skala fra 0 til 10), til enten ERGO alene (standardbehandling) eller IPET+ERGO (interventionsgruppen) (36). Randomiseringen blev gennemført i databasen REDCap. På grund af interventionens karakter kunne deltagerne ikke blindes for gruppetilhør, men den statistiske analyse og fortolkning blev udført blindet.

Deltagerne var primære og assisterende abdominal- og bækkenkirurger inden for gynækologi, urologi eller mave-tarm kirurgi, der i gennemsnit udførte mindst fire timers

kirurgi om ugen. For at kunne blive inviteret til fase 2, var det en forudsætning at man havde besvaret fase 1 ERGO spørgeskemaet.

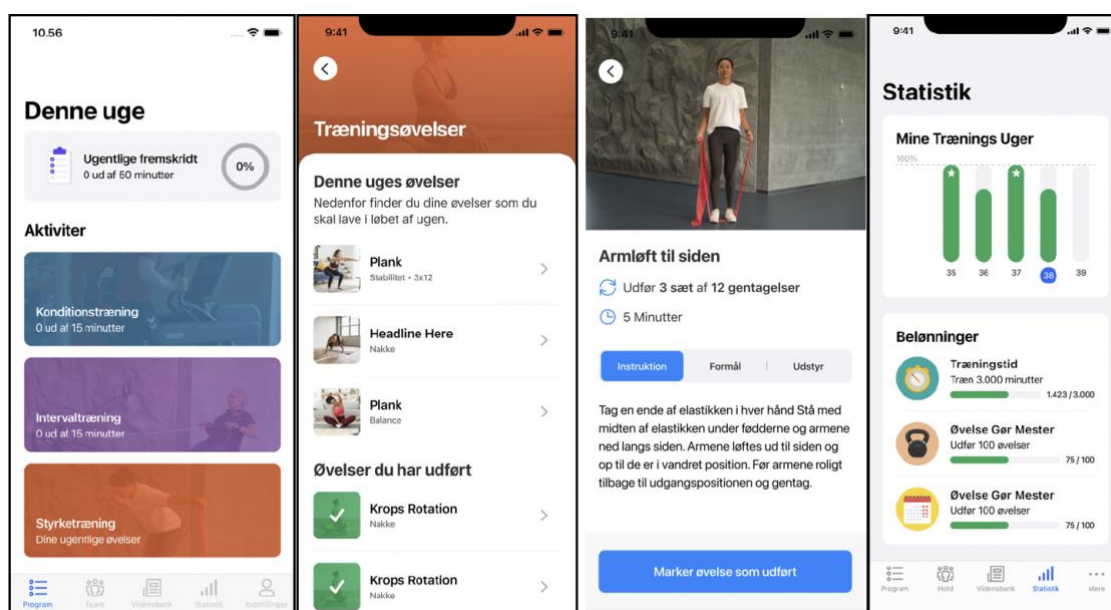
Intelligent Motion

Alle deltagere fik ERGO som standardbehandling og blev opfordret til at fortsætte med at praktisere komponenterne i samme omfang som i fase 1. Interventionsgruppen modtog derudover deres træningsprogram via app'en Intelligent Motion, der bygger på konceptet af samme navn (25, 33). App'en genererer et ugentligt 50-minutters program tilpasset jobprofil, fysisk kapacitet og generelle helbredsindikatorer, herunder smerter. De første 20 minutter tildeles efter deltagerens jobprofil, f.eks. ordineres et stillesiddende job moderat til høj konditionstræning svarende til en Borg-vurdering af anstrengelse på 14-15 (31, 43), og de resterende 30 minutter sammensættes efter den individuelle profil med konditions-, styrke-, funktionel- og balance træning.

De 50 minutter kunne udføres samlet eller deles op i 2-5 kortere sessioner med samme effekt (44). Tabel 1 viser de selvrapporterede variable og deres grænseværdier, som app'en bruger til at skræddersy programmet. Figur 1 viser screenshots fra appen.

Domæne	Variabel	Tilpasning af program
Jobprofil	Fysiske krav i hovedjobbet (stillesiddende, stående/gående, fysisk tungt)	Bestemmer de første 20 minutter, fx konditionstræning ved stillesiddende arbejde og udholdenhedstræning ved fysisk tungt arbejde
BMI	Højde og vægt	BMI over 25 udløser ekstra konditionstræning
Fysisk kapacitet	Selv vurderet kondition og muskelstyrke (0-10) sammenlignet med jævnaldrende	Scorer under 5 (gennemsnit) udløser ekstra konditions- eller styrketræning
Balance og funktion	Selvtest af stående balance på ét ben	Tab af balance før 30 sekunder udløser funktionel- og balance træning
Helbredsprofil	Smerter i specifikke kropsregioner (ja/nej og intensitet 0-10)	Symptomer udløser specifik styrketræning for den smertende region; intensiteten styrer prioriteringen

Tabel 1. Selvrapporterede variable og grænseværdier, som app'en Intelligent Motion anvender til at skræddersy det individuelle træningsprogram.



Figur 1: Screenshots fra appen Intelligent Motion.

Outcomes og målinger

Outcomes blev målt med online-spørgeskemaer ved baseline, 12 uger og 20 uger, hvor 20 uger var det primære tidspunkt. Det primære outcome var 20 ugers forskellen mellem grupperne i den værste 3-måneders smerteintensitet identificeret ved baseline, målt med en modificeret version af det nordiske spørgeskema (45, 46) på en skala fra 0 til 10. For hver kropsregion angav deltageren først antal dage med smerter de seneste tre måneder og derefter, hvis smerter mindst én dag, smerteintensiteten. Den værste smerte blev defineret som den højeste rapporterede intensitet ved baseline på tværs af de ti vurderede regioner (nakke, øvre ryg, lænd, skuldre, albuer, håndled/hænder, hofter, knæ og ankler/fødder). Dette outcome blev valgt, fordi IPET netop tilpasser programmet efter den enkeltes værste smerteregeion.

Sekundære smerte outcomes omfattede 7-dages smerteintensitet, antal dage med smerter, antal dage hvor smerter påvirkede arbejde eller privatliv, brug af smertestillende, smertestatus (smertecases, intensitet på mindst 3) og multisite-smerter (smerter i to eller flere regioner). Andre outcomes omfattede generelt helbred målt med Short Form 12 (47), udbrændthed målt med Copenhagen Burnout Inventory (48) og

arbejdsevne målt med Work Ability Index (49). Ved baseline blev desuden registreret demografiske og arbejdsmæssige forhold, fysisk aktivitetsniveau (50), selv vurderet fysisk kapacitet (51) og ugentlig tid brugt på fysisk aktivitet (52). Selvrapporteret adherence til både ERGO samt IPET blev målt ved 12 og 20 uger.

Statistiske analyser

Den primære analyse fulgte intention-to-treat-princippet (alle randomiserede deltagere indgår i den gruppe, de blev tildelt) og anvendte en lineær mixed-model, der håndterer den indbyrdes korrelation mellem gentagne målinger fra samme deltager og inddrager alle tilgængelige observationer under antagelsen om at manglende data er tilfældigt fordelt. Den nødvendige stikprøvestørrelse blev beregnet til 58 deltagere ud fra en klinisk relevant forskel på 1,5 point, en fælles standardafvigelse på 2,0 point, et signifikansniveau på 0,05 og en styrke på 80 % (53). Med et forventet frafald på 30 % var rekrutteringsmålet 83 deltagere. Der blev gennemført forud specificerede tillægsanalyser: en justeret analyse (for alder, køn, kropsvægt, ugentlig arbejdstid, speciale og fysisk aktivitet), en complete-case-analyse og en per-protokol-analyse blandt deltagere med selvrapporteret IPET adherence på minimum 70%. Alle analyser blev udført i Stata version 17.

04 Resultater

04.01 Studie 1: Systematisk litteraturstudie

Litteratursøgningen identificerede 25 egnede studier. Med én undtagelse var alle observationelle, herunder syv pilotstudier og to feasibility studier. Den samlede metodologiske kvalitet blev vurderet som rimelig, og der var betydelig heterogenitet på tværs af design, populationer og metoder. Stikprøverne varierede fra vurderinger af en enkelt kirurg til 141 deltagere, og studierne var gennemført i Nordamerika (10), Europa (9) og Asien (6). Tre studier blev vurderet som gode, 18 som rimelige og fire som ringe,

hovedsageligt på grund af små stikprøver, ufuldstændig rapportering af udvælgelses- og rekrutteringsprocedurer og manglende styrkeberegninger.

Den narrative syntese resulterede i fem overordnede kategorier efter den primære interventionskomponent. Tabel 2 sammenfatter fundene på interventionsniveau.

Interventionstype	Antal	Vigtigste fund
Ergonomisk uddannelse	6	Forelæsninger, workshops, webinarer og oplæring i ergonomiske principper. Forbundet med en reduktion i andelen af kirurger, der rapporterede smerter. Ét cluster-randomiseret forsøg viste lavere forekomst af lændesmerter i interventionsgruppen. Effekterne var svære at isolere, da uddannelse ofte var kombineret med andre elementer.
Mikropauser	4	Korte intraoperative pauser (10 sekunder til 5 minutter, med eller uden strækøvelser). Forbundet med reduktion i absolut smerteintensitet i overkroppen og i selvrapporteret muskeltræthed, særligt i længere indgreb. Et enkelt studie fandt ingen effekt.
Optimering af arbejdsstilling	6	Justering af opstilling, skærmlacering, robotkonsol og brug af visuelle hjælpemidler. Forbundet med forbedrede arbejdsstillinger og biomekaniske mål (fx nakkevinkler og posturale risikoscorer), men ikke konsistent med lavere selvrapporteret smerte.
Kropsstøtteanordninger	4	Overkrops-exoskeletter og benstøtte. Reducerede tid i belastende skulderstillinger i nogle studier, men uden konsistente effekter på selvrapporteret smerte.
Diverse ergonomiske anordninger	5	Heterogene og ikke direkte sammenlignelige. To studier af anti-træthedsmåtter var forbundet med lavere smerteintensitet og træthed, mens fx ergonomiske operationsstole ikke viste effekt.

Tabel 2. De fem interventionstyper identificeret i Studie 1, antal studier og retningen af fundene.

Kategorien ergonomisk uddannelse omfattede seks studier, mikropauser fire studier, optimering af arbejdsstilling seks studier, kropsstøtteanordninger fire studier og diverse anordninger fem studier. De enkelte studier, deres design og resultater er gengivet i afhandlingens Paper I. På trods af de metodiske begrænsninger pegede reviewet på tre pragmatiske interventionstyper med beskedne, men relativt konsistente positive fund: ergonomisk uddannelse, mikropauser og optimering af arbejdsstilling. Disse tre interventionskategorier blev derfor lagt til grund for udviklingen af ERGO og designet af fase 1 i Studie 2.

04.02 Studie 2, fase 1: Lancering og udbredelse af God Ergonomi

Tolv afdelinger blev inviteret, og ni indvilligede i at deltage (én var allerede involveret i et andet forskningsprojekt, én fandt studiet irrelevant, og én reagerede ikke yderligere). ERGO blev lanceret på fem danske hospitaler (tre regionale og to universitetshospitaler) mellem oktober 2023 og oktober 2025. På tværs af hospitalerne deltog ni kirurgiske afdelinger: Mave-tarm kirurgi (3), gynækologi (3) og urologi (3).

Det opfølgende spørgeskema blev sendt til 313 potentielle deltagere, hvoraf 104 kirurger (33 %) besvarede det. Samlet rapporterede 96 %, at de havde set eller hørt om ERGO. Det mundtlige oplæg ved morgenmøder var den hyppigst angivne kilde (78 %) efterfulgt af plakater i operationsstuen (72 %) og på afdelingen (53 %). Kendskabet til begge komponenter var moderat til højt: 93 % angav i det mindste et vist kendskab til de ergonomiske arbejdsstillinger og 89 % til mikropauserne.

Kendskabet var imidlertid højere end praktiseringen, særligt for mikropauser. Hele 85 % rapporterede, at de praktiserede de ergonomiske arbejdsstillinger det meste af tiden eller altid, mens kun 34 % praktiserede mikropauser tilsvarende ofte (Tabel 3). På tværs af begge komponenter var højere kendskab forbundet med mere konsistent praksis.

Svarkategori	Ergonomiske arbejdsstillinger	Mikropauser
Altid	21 %	4 %
Det meste af tiden	64 %	30 %
Nogle gange	8 %	26 %
Sjældent	4 %	25 %
Aldrig	1 %	12 %

Tabel 3. Selvrapporteret praktisering af de to komponenter i God Ergonomi (fase 1, n = 104). Resterende andele svarede „ved ikke”.

Blandt de kirurger, der sjældent praktiserede mikropauser, var de hyppigst angivne barrierer manglende støtte fra det øvrige operationspersonale (57 %), fra kirurgkolleger (42 %) og manglende oplæring (37 %). For arbejdsstillinger var den vigtigste barriere manglende oplæring. Operationssygeplejersken var den hyppigst angivne påmindelse om mikropauser (77 %), hvilket understreger personalets vigtige rolle.

Begge komponenter blev opfattet positivt på et principielt plan: de fleste var enige i, at både ergonomiske arbejdsstillinger og mikropauser er gode måder at forebygge smerter på (85 % og 75 %), og at alle bør følge anbefalingerne (93 % og 85 %). Opfattelserne blev dog mere forbeholdne, når fokus skiftede fra den generelle værdi til den praktiske anvendelse. For mikropauser angav kun 13 %, at det var let at huske dem. Samlet tyder mønsteret på, at justering af arbejdsstilling lettere lod sig integrere i den enkelte kirurgs rutine, mens mikropauser i højere grad afhang af social støtte i teamet, påmindelser og tilpasning til arbejdsgangen.

Muskelskeletsmerter var fortsat udbredte i populationen: 74 % rapporterede smerter i det mindste nogle gange, og blandt disse havde 79 % smerter i to eller flere kropsregioner. Smertefrekvensen var ikke associeret med højere kendskab eller praksis, selvom der var en (ikke-signifikant) tendens til mere mikropause-praksis blandt kirurger med hyppigere frekvens af smerter.

04.03 Studie 2, fase 2: Effekten af at tilføje fysisk træning

Af de 104 inviterede kirurger blev 85 vurderet for egnethed, og 83 (80 %) blev randomiseret til enten IPET+ERGO (n = 41) eller ERGO alene (n = 42). Ved opfølgning, forelå der besvarelser for primær outcome for 66 deltagere ved 12 uger (80 %) og 60 deltagere ved 20 uger (72 %). Den første deltager blev inkluderet i december 2023, og den sidste opfølgning blev modtaget i maj 2026.

Deltagernes udgangspunkt

Baseline karakteristika var sammenlignelige på tværs af de to grupper. Samlet fordelte kirurgerne sig ligeligt indenfor de tre specialer: gynækologi (27 %), urologi (36 %) og mave-tarm kirurgi (34 %). Gennemsnitsalderen var 48,4 år, 64 % var kvinder, og den gennemsnitlige ugentlige arbejdstid var 40,6 timer. Hele 98 % rapporterede smerter inden for de seneste tre måneder på en skala fra 0 til 10, 92 % havde multisite-smerter, og 72 % kunne kategoriseres som smertecase (intensitet på mindst 3 i en given

kropsregion). Den gennemsnitlige værste smerteintensitet var 3,8 og de hyppigst ramte regioner var nakke (29 %), lænd (23 %), knæ (13 %) og skuldre (11 %). Deltagerne vurderede deres fysiske kapacitet til at være lidt over jævnaldrendes, og 43 % rapporterede mindst 150 minutters moderat fysisk aktivitet om ugen.

Primært outcome: værste smerteintensitet

I den primære intention-to-treat-analyse var der ingen statistisk signifikant forskel mellem grupperne i den værste smerteintensitet ved 20 uger (IPET+ERGO vs. ERGO: 0,54; 95 % konfidensinterval -0,41 til 1,50; $p = 0,266$). Interventionen viste altså ikke, at tilføjelsen af IPET reducerede den værste smerte mere end ERGO alene. **Begge grupper** reducerede dog den værste smerte fra baseline til 20 uger med henholdsvis cirka 1,4 point (IPET+ERGO) og 1,7 point (ERGO), hvilket ligger inden for det interval, der almindeligvis betragtes som klinisk relevant (53). Reduktionen skete primært fra baseline til 12 uger, hvorefter niveauet var relativt stabilt. Tabel 4 viser de primære og vigtigste sekundære smerte outcomes.

Outcomes (ved 20 uger)	IPET+ERGO	ERGO	Forskel (95 % CI), p
Værste smerteintensitet, 3 mdr.	2,50	1,95	0,54 (-0,41 til 1,50); $p = 0,27$
Værste smerteintensitet, 7 dage	2,27	1,30	0,97 (0,00 til 1,95); $p = 0,049$
Smertecase (intensitet ≥ 3)	43 %	28 %	8,46 (0,39 til 181,53); $p = 0,17$
Multisite-smerter (≥ 2 regioner)	71 %	75 %	0,58 (0,16 til 2,04); $p = 0,39$
Dage med smerter (≥ 1 dag, 3 mdr.)	71 %	63 %	1,66 (0,59 til 4,70); $p = 0,34$
Smertestillende ≥ 1 gang/md.	39 %	16 %	2,70 (0,75 til 9,68); $p = 0,13$

Tabel 4. Primære og udvalgte sekundære outcomes ved 20 uger. Positive forskelle angiver højere værdier i IPET. For kontinuerlige outcomes vises modeestimerede gennemsnit, for kategoriske outcomes odds ratio.

Sekundære outcomes

De sekundære smerte outcomes viste ikke et konsistent mønster til fordel for nogen af grupperne. Det eneste sekundære outcome med en statistisk signifikant forskel var

værste smerteintensitet de seneste syv dage, der favoriserede ERGO (0,97; 95 % CI 0,00 til 1,95; $p = 0,049$). Andre sekundære outcomes for generelt helbred, arbejdsevne og udbrændthed adskilte sig ikke statistisk mellem grupperne; her kan høje udgangsværdier (kirurgerne vurderede generelt deres helbred og arbejdsevne højt gennem hele forløbet) have begrænset muligheden for at måle forbedringer. Begge grupper øgede dog deres selvvaluerede muskelstyrke og kondition signifikant fra baseline til 20 uger.

Den selvrapporterede adherence var lav. Af de 41 deltagere i IPET+ERGO rapporterede 24 deres træningsmængde ved 20 uger; den gennemsnitlige dosis var 32 minutter om ugen, og kun 9 deltagere (22 % af gruppen) nåede den fastsatte tærskel på minimum 70 % (≥ 35 minutter om ugen) som i andre studier er forbundet med klinisk relevante og statistisk signifikante forbedringer (35). Blandt de ni deltagere der trænede minimum 70 % om ugen, var den gennemsnitlige ugentlige dosis 58 minutter, altså mere end det foreskrevne program på 50 minutter om ugen. Praktiseringen af ERGO var fortsat ujævn mellem de to komponenter. Ved 20 uger rapporterede 94 % at praktisere de ergonomiske arbejdsstillinger ofte, mod kun 22 % for mikropauserne. Per-protokol-analysen, justerede analyser og complete-case analyserne ændrede ikke fortolkningen (36).

05 Diskussion

05.01 Hovedfund

Projektet havde et tredelt sigte: at identificere ergonomiske interventioner med positiv betydning for kirurgers muskelskelethelbred, at omsætte denne viden til evidensbaserede anbefalinger og lancere dem bredt, og at teste den yderligere effekt af fysisk træning (IPET). I det systematiske litteraturstudie var ergonomisk uddannelse mest konsistent forbundet med en reduktion i andelen af kirurger med smerter, mikropausers reduktion i absolut smerteintensitet og træthed, og optimering af arbejdsstilling med forbedringer i biomekaniske mål. Den efterfølgende lancering af ERGO gav højt kendskab til begge komponenter, men ujævn praksis, med mindre

konsekvent brug af mikropauser. I det randomiserede forsøg gav tilføjelsen af app-leveret IPET ikke en statistisk signifikant forskel mellem grupperne i den værste smerte målt ved baseline, men begge grupper opnåede en klinisk relevant reduktion.

05.02 At reducere arbejdskravene gennem ergonomi

Ergonomiske interventioner anbefales af nationale arbejdsmiljømyndigheder og europæiske organer til forebyggelse af muskelskelet smerter i sundhedssektoren (2, 26), og systematiske oversigter efterlyser større opmærksomhed på ergonomisk oplæring på tværs af kirurgiske specialer (3, 14, 54). Den brede opbakning betyder dog ikke, at evidensen for de specifikke tiltag er entydig. I Studie 1 viste ergonomisk uddannelse, mikropauser og optimering af arbejdsstilling de mest konsistente positive fund, men den samlede evidens var begrænset af betydelig heterogenitet og beskeden kvalitet.

Det fysiologiske rationale for disse interventionstyper er ikke desto mindre veletableret. Kirurgisk arbejde kræver ofte langvarige statiske stillinger og vedvarende lav muskelaktivitet, og kirurgens opmærksomhed er så rettet mod opgaven og patienten, at bevidstheden om akkumulerende belastning kan være begrænset (55). Over tid kan dette øge det intramuskulære tryk, hæmme den lokale blodgennemstrømning og fremme ophobning af affaldsstoffer, hvilket bidrager til udtrætning og smerter (16). Det kan forklare det mønster i Studie 1, hvor mikropauser viste størst effekt ved indgreb over to timer og samtidig forbedrede mentalt fokus (41, 56, 57). En tilsvarende forsinkelse mellem biomekanisk forbedring og oplevet smertelindring kan forklare, hvorfor stillingsoptimering hyppigere forbedrede objektive mål end selvrapporteret smerte, og evidens fra blandede arbejdsgrupper tyder på, at varige effekter kan kræve længere interventionsperioder (58). I tråd hermed havde studierne, der havde de længste opfølgingsperioder, også de mest konsistente reduktioner i andelen med smerter.

Ergonomisk bevidsthed og praksis i kirurgien

Trods øget opmærksomhed er ergonomiske principper fortsat ikke systematisk integreret i den kirurgiske uddannelse eller den daglige praksis (5, 14, 54). Dette gab opstår tidligt i uddannelsesforløbet, da medicinstudiet og hospitalerne kun giver lidt formel ergonomisk undervisning (28). Relativt enkle undervisningssessioner kan forbedre bevidstheden og fremme praksis (29, 30), hvilket blev bekræftet i fase 1, hvor en kort introduktion gav højt kendskab og hyppig praktisering af arbejdsstillinger. Praksis adskilte sig dog mellem komponenterne: mikropauser blev praktiseret mindre konsekvent, sandsynligvis fordi de, i modsætning til individuelle stillingsændringer, afhænger af koordinering med operationsteamet. Mere konsekvent mikropause-praksis kan derfor kræve større opmærksomhed på den organisatoriske dimension gennem struktureret introduktion, ledelsesopbakning og integration i arbejdsgangen (59, 60).

En dimension, projektet ikke direkte adresserede, er kønsperspektivet. De ergonomiske udfordringer for kvindelige kirurger fortjener særlig opmærksomhed, da andelen af kvinder i kirurgiske specialer er steget støt (61), mens operationsstuer og instrumenter historisk er designet ud fra mandlig anatomi, hvilket stiller kvindelige og småhåndede kirurger ergonomisk ringere (62).

05.03 At øge kapaciteten gennem fysisk træning

Tilføjelsen af app-leveret IPET til God Ergonomi gav ikke en statistisk signifikant forskel mellem grupperne i den værste smerte ved 20 uger. Dette står i kontrast til en stor del af den hidtidige evidens, hvor IPET på tværs af arbejdsgrupper har vist gavnlige effekter på smerter, fysisk kapacitet og produktivitet (34), med de største smertereduktioner blandt deltagere med høj træningsadherence (58). Et forsøg blandt militære helikopterpiloter fandt tilsvarende ingen forskel mellem grupperne, men signifikante reduktioner inden for grupperne og lav træningsadherence (63), og et lignende mønster sås blandt kontoransatte (64). Den manglende tillægseffekt bør fortolkes i lyset af flere sammenhængende forhold.

Lav adherence og ukendt træningskvalitet

Den mest sandsynlige forklaring er lav adherence til IPET og dermed ukendt træningskvalitet. For at træningen kan øge kapaciteten og reducere smerter, skal den udføres i tilstrækkelig dosis og med høj intensitet. I dette forsøg var adherence lav, og det blev ikke målt i detaljer, om øvelserne blev udført med tilstrækkelig belastning og progression, begge afgørende for muskulær tilpasning og smertereduktion (34). Begge grupper øgede ganske vist deres selvvaluerede styrke, men det kan ikke bekræftes, om det afspejler en reel træningseffekt. At stigningen var ens i begge grupper, kan tyde på, at nogle deltagere i ERGO trænede mere på egen hånd, en form for kontaminering, der kan have bidraget til smertereduktionen i kontrolgruppen.

God Ergonomi som aktiv sammenligningsgruppe

En anden forklaring er, at ERGO fungerede som en aktiv sammenligningsgruppe snarere end en passiv kontrol. I modsætning til de fleste tidligere forsøg, der sammenlignede træning med ingen behandling, sammenlignede dette forsøg IPET+ERGO med ERGO alene. Begge grupper reducerede den værste smerte med cirka 1,4-1,7 point, reduktioner, der falder inden for det klinisk relevante interval (53) og svarer til det, der er rapporteret efter ergonomisk uddannelse og mikropausur blandt kirurger (30, 56, 57). Det rejser muligheden for, at ergonomisk bevidsthed, bedre arbejdsstillinger og muskulær restitution gennem mikropausur i sig selv bidrager til smertereduktion. Den uafhængige effekt af ERGO kan dog ikke bekræftes ud fra dette design, og evidensen for ergonomiske interventioner blandt fysisk belastede arbejdstagere er fortsat blandet (65). Uanset hvad betød den aktive sammenligningsgruppe, at enhver ekstra effekt af træningen skulle overgå en allerede virksom indsats, hvilket kan have været svært at nå givet den lave adherence og stikprøvestørrelsen.

Leveringsformen for IPET

En tredje forklaring er leveringsformen. I mange tidligere forsøg blev IPET leveret på eller nær arbejdspladsen, ofte i arbejdstiden og med en vis supervision eller

organisatorisk støtte (25). I dette forsøg blev træningen leveret via en app, og kirurgerne blev opfordret til selv at indpasse den i deres hverdag, eventuelt opdelt i kortere sessioner (44). Det ser ud til at have været utilstrækkeligt i en travl klinisk hverdag med uforudsigelige arbejdsprogrammer. I modsætning til mange tidligere undersøgte faggrupper er kirurgers opmærksomhed i arbejdstiden rettet mod patienten og operationer, hvilket levner lidt plads til sundhedsadfærd som f.eks. IPET (66), og nogle kirurger er tilbageholdende med at træne i arbejdstiden, da de opfatter den som forbeholdt patientbehandling (67). App-leveringen flyttede dermed meget af initiativet over på den enkelte. Fraværet af supervision kan yderligere have påvirket både motivation og træningskvalitet (68), og app'en gennemgik flere opdateringer undervejs som led i tilpasningen til de amerikanske sites. Forsøget testede dermed reelt, om en app-baseret form med lav støtte kunne integreres i kirurgers hverdag, og det kunne den ikke i tilstrækkelig dosis.

05.04 Implementering i en kirurgisk kontekst

Ud over den individuelle efterlevelse var implementering på team- og organisationsniveau en central barriere, der påvirkede både ERGO og IPET. Operationssygeplejersken var den hyppigste påmindelse om mikropauser, men teamet som helhed blev ikke direkte målrettet i nogen af indsatserne, og mikropause-praksis afhang derfor af individuelt initiativ i et team uden særlig forberedelse (38). Kollega- og teamstøtte er identificeret som vigtige facilitatorer for adfærdsændring i operationsstuen, og netop manglende støtte fra personale og kolleger var de hyppigste barrierer mod mikropauser.

På organisationsniveau var ledelsesinddragelsen minimal. Det var et bevidst valg for at gøre deltagelsen så let som muligt for afdelingerne, men i bakspejlet kan det have været en væsentlig begrænsning. Uden synlig organisatorisk opbakning, beskyttet tid eller lokal facilitering konkurrerede både ERGO og IPET med de eksisterende krav i stedet for

at være indlejret i dem. Tidligere implementeringsforskning peger på, at arbejdspladsindsatser lykkes bedre, når de støttes af ledelsen, integreres i eksisterende rutiner og faciliteres af lokale ildsjæle (60, 66, 69), betingelser, der ikke systematisk var til stede her. Rekrutteringen var vanskelig trods en lang periode og involvering af flere 'kendte figurer' i dansk kirurgi, hvilket afspejler et bredere spændingsfelt mellem de veldokumenterede konsekvenser af kirurgers smerter og den begrænsede kapacitet til at prioritere deltagelse. Det kan afspejle en kirurgisk kultur, hvor fysisk ubehag normaliseres, og hvor egen sundhed kommer i anden række efter patientbehandlingen (55).

05.05 Metodiske overvejelser

Studierne havde også metodiske begrænsninger. Litteraturstudiet anvendte en inklusiv tilgang til studiedesign, fordi der var forventet få randomiserede forsøg, hvilket resulterede i overvejende observationelle studier og dermed svagere evidens. For at muliggøre ensartet kvalitetsvurdering blev Downs & Black-tjeklisten anvendt på alle designs (40). Udelukkelsen af simulationsstudier styrkede den kliniske relevans, men begrænsede eksperimentel kontrol (39). I Studie 2, fase 1 betød den lave svarprocent (33 %), at fundene er begrænset til dem, der svarede, og kirurger med særlig interesse for ergonomi kan være overrepræsenteret. Det tværsnitsbaserede design uden baselinemåling betyder, at kendskab og praksis ikke entydigt kan tilskrives lanceringen af ERGO.

I Studie 2, fase 2 forhindrede fraværet af en tredje gruppe uden behandling, at ERGO og IPET kunne vurderes hver for sig. Individuel randomisering blev valgt, fordi ERGO blev leveret på afdelingsniveau og træningen ordineret individuelt, men variationen i lanceringen mellem afdelinger taler for, at en cluster-randomisering kunne have været mere hensigtsmæssig. Kun kirurger, der besvarede fase 1-skemaet, kunne indgå i fase 2, hvilket kan have medført en udvælgelse af de mest engagerede. Frafaldet ved opfølgning

lå inden for det forventede (30 %), men det er ukendt, om det var tilfældigt eller systematisk. Samlet reducerede de manglende data præcisionen, men de justerede analyser og complete-case-analyser ændrede ikke det overordnede fund.

06 Konklusion

Projektet Smertefri kirurger havde til formål at udvikle, lancere og evaluere strategier til håndtering af muskelskelet smerter blandt abdominal- og bækkenkirurger ud fra en trinvis tilgang fra evidenssyntese over interventionsudvikling og -lancering til effekttest.

Det systematiske litteraturstudie identificerede ergonomisk uddannelse, mikropauser og optimering af arbejdsstilling som de interventionstyper, der mest konsistent var forbundet med forbedringer i kirurgers muskelskelethelbred. Evidensgrundlaget var dog begrænset af heterogene designs, små stikprøver og varierende kvalitet. Ved alene at inkludere interventioner afprøvet i reelle operationsstuer giver studiet et mere klinisk forankret evidensgrundlag end tidligere tilgængeligt.

Efter lanceringen af God Ergonomi på ni danske kirurgiske afdelinger var kendskabet til begge komponenter højt, men praktiseringen ujævn. Justering af arbejdsstilling blev praktiseret konsekvent af de fleste kirurger, mens mikropauser blev praktiseret mindre regelmæssigt, sandsynligvis fordi de afhænger af teamets støtte. En lavintensiv lancering kan altså skabe højt kendskab, men de to komponenter står over for fundamentalt forskellige implementeringsudfordringer: arbejdsstillinger kan justeres individuelt, mens mikropauser afhænger af teamet.

I det randomiserede forsøg gav tilføjelsen af app-leveret fysisk træning (IPET) til God Ergonomi (ERGO) ikke en statistisk signifikant forskel mellem grupperne i den værste smerte ved 20 uger. Begge grupper reducerede dog smerterne inden for det klinisk relevante interval. De mest sandsynlige forklaringer på den manglende tillægseffekt af IPET var lav træningsadherence og det forhold, at ERGO udgjorde en aktiv

sammenligningsgruppe og ikke en passiv kontrol. Reelt testede forsøget, om app-leveret IPET uden instruktion, supervision, organisatorisk støtte og beskyttet træningstid kunne integreres i kirurgernes dagligdag, og under disse betingelser blev træningen ikke leveret i tilstrækkelig dosis til at give en målbar tillægseffekt.

Samlet peger resultaterne på et bredere mønster: både ergonomisk praksis og fysisk træning er fornuftige strategier til at håndtere kirurgers muskelskeletsmarter, men ingen af dem er sandsynligvis tilstrækkeligt effektive, når de tilbydes som et tillæg til eksisterende kliniske krav uden strukturel forankring. Den centrale lære er, at strategiernes effekt i høj grad afhænger af de betingelser, hvorunder de leveres. På sigt kan det kræve et bredere kulturskifte i kirurgien, hvor ergonomisk praksis og fysisk kapacitet anerkendes som faglige prioriteter frem for den enkeltes ansvar.

07 Perspektiver og anbefalinger

Muskelskeletsmarter blandt kirurger er udbredte og har konsekvenser for både den enkelte og for sundhedsvæsenets kapacitet. Projektets resultater peger på, at forebyggelse kræver handling på flere niveauer, ikke kun hos den enkelte kirurg, men også i operationsteamet, på afdelingen og i hospitalsledelsen. Følgende anbefalinger er rettet mod disse niveauer.

Ergonomi skal være del af den daglige rutine

Ergonomisk uddannelse og justering af arbejdsstilling er et gennemførligt og lavtærskel-udgangspunkt for forebyggelse, fordi den enkelte kirurg i vid udstrækning selv kan justere sin stilling uden at ændre teamets adfærd. En kort ergonomisk tjek af bordhøjde, skærmlacering og hensigtsmæssig arbejdsstilling kan med fordel indbygges i den eksisterende time-out-procedure før operation, så ergonomi forankres i den rutinemæssige arbejdsgang (59).

Mikropauser kræver en teamkultur

Mikropauser forudsætter en fælles forståelse af deres formål, en arbejdsgang der giver plads til dem, og en teamkultur hvor korte pauser accepteres frem for at opfattes som forstyrrelser. Fremtidige indsatser bør derfor aktivt inddrage hele operationsteamet, operationssygeplejersker, anæstesipersonale og øvrigt personale, frem for at hvile på den enkelte kirurg alene. På grund af den høje personaleudskiftning bør dette gøres som en del af onboarding eller med jævne mellemrum på personalemøder.

Fysisk kapacitet kræver støtte for at virke

Fysisk træning, her IPET, er en relevant strategi, men app-leveret træning uden instruktion og opbakning blev i dette projekt ikke gennemført i tilstrækkelig dosis til at give en målbar tillægseffekt. For at træning skal virke, peger resultaterne på behovet for en indledende periode med instruktion eller supervision til øvelserne, beskyttet træningstid og lokal facilitering. Kun sådan, kan der sikres tilstrækkelig dosis og kvalitet. Alternativt kan selv små mængder progressiv styrketræning, f.eks. få minutter dagligt være tilstrækkelige, hvis de udføres regelmæssigt og med tilstrækkelig belastning (70).

Organisatorisk forankring og ledelsesopbakning

Forebyggende indsatser kan næppe fastholdes på afdelingsniveau uden synlig institutionel og ledelsesmæssig opbakning, beskyttet tid og integration af ergonomi og fysisk sundhed i eksisterende personalepolitikker og arbejdsmiljøarbejde (66, 69). Uden dette risikerer både ERGO og IPET at blive oplevet som ekstra krav, der pålægges i forvejen pressede klinikere, frem for som understøttede og værdsatte dele af arbejdslivet. Indsatserne understøtter i øvrigt, frem for at underminere, produktiviteten: mikropauser forlænger ikke operationstiden, men hjælper med at fastholde fokus (41), og IPET har i andre sammenhænge øget produktiviteten og reduceret sygefravær (71).

Forankring i uddannelse

På langt sigt kan det være mere effektivt at integrere ergonomisk uddannelse og opmærksomhed på fysisk kapacitet i kirurgers specialeuddannelse og kliniske

onboarding end at rette indsatsen mod kirurger, der allerede er etablerede i praksis. På den måde påbegynder kirurger deres karriere med normer, der prioriterer ergonomi og fysisk kapacitet. Ergonomisk onboarding kan med fordel gøres til et formelt krav på linje med andre sikkerhedsprocedurer som steril teknik og kirurgisk time-out.

Perspektiver for forskningen

Fremtidige forsøg bør overveje et design med tre eller fire grupper, der kan adskille bidraget fra henholdsvis ERGO og IPET, gerne med et cluster-randomiseret design, der sikrer en klarere adskillelse mellem afdelinger. For IPET bør fremtidige forsøg overveje supervision, i det mindste indledningsvis sammen med beskyttet træningstid og lokal facilitering. Hele operationsteamet bør inddrages som aktiv målgruppe, og en kvalitativ undersøgelse af kirurgers erfaringer med deltagelse kan give værdifuld indsigt i de implementeringsudfordringer, projektet afdækkede. Mere generelt vil feltet have gavn af større stikprøver, længere interventions- og opfølgningsperioder samt standardiserede outcomes, så studier bedre kan sammenlignes.

08 Referencer

1. de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Luxembourg: European Agency for Safety and Health at Work; 2019.
2. Clarke M, Vroonhof P, Snijders J, de Winter T, van Scheijndel P, van Dorst P, et al. Musculoskeletal health and risk factors in the health and social care sector – a review of existing information. Luxembourg: European Agency for Safety and Health at Work; 2025.
3. Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of Work-Related Musculoskeletal Disorders Among Surgeons and Interventionalists: A Systematic Review and Meta-analysis. *JAMA Surg.* 2018;153(2):e174947.
4. GlobalData Plc. The Complexities of Physician Supply and Demand: Projections From 2021 to 2036. Washington, DC: Association of American Medical Colleges; 2024.
5. Stucky CH, Cromwell KD, Voss RK, Chiang YJ, Woodman K, Lee JE, et al. Surgeon symptoms, strain, and selections: Systematic review and meta-analysis of surgical ergonomics. *Ann Med Surg (Lond).* 2018;27:1-8.
6. Dalager T, Sogaard K, Boyle E, Jensen PT, Mogensen O. Surgery Is Physically Demanding and Associated With Multisite Musculoskeletal Pain: A Cross-Sectional Study. *J Surg Res.* 2019;240:30-9.
7. Bishop AG, Uhl TL, Zwischenberger JB, Meyerson SL. Prevalence and Impact of Musculoskeletal Pain Due to Operating Among Surgical Trainees. *J Surg Educ.* 2023;80(5):676-81.
8. Steadman S, Seibel C, Hallbeck MS, Norasi H, Zhang A, Chrouser K. The impact of work-related pain on surgical team members' burnout and personal and professional performance. *Am J Surg.* 2025;250:116508.
9. Møller CM, Clausen T, Aust B, Eiberg JP. A National Study on Burnout and Pain in Vascular Surgery. *Eur J Vasc Endovasc Surg.* 2026. Epub ahead of print. doi: 10.1016/j.ejvs.2026.02.039.
10. Phongamwong C, Deema H. The impact of multi-site musculoskeletal pain on work ability among health care providers. *J Occup Med Toxicol.* 2015;10(1):21.
11. Davis WT, Fletcher SA, Guillaumondegui OD. Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. *J Surg Res.* 2014;189(2):207-12.e6.
12. AlSabah S, Al Haddad E, Khwaja H. The prevalence of musculoskeletal injuries in bariatric surgeons. *Surg Endosc.* 2019;33(6):1818-27.
13. Alleblas CC, Formanoy MA, Konemann R, Radder CM, Huirne JA, Nieboer TE. Ergonomics in gynecologists' daily practice: A nationwide survey in The Netherlands. *Work.* 2016;55(4):841-8.
14. Barrios EL, Polcz VE, Hensley SE, Sarosi GA, Mohr AM, Loftus TJ, et al. A narrative review of ergonomic problems, principles, and potential solutions in surgical operations. *Surgery.* 2023;174(2):214-21.

15. Szeto GPY, Cheng SWK, Poon JTC, Ting ACW, Tsang RCC, Ho P. Surgeons' Static Posture and Movement Repetitions in Open and Laparoscopic Surgery. *J Surg Res.* 2012;172(1):e19-e31.
16. Sogaard K, Sjøgaard G. Physical Activity as Cause and Cure of Muscular Pain: Evidence of Underlying Mechanisms. *Exerc Sport Sci Rev.* 2017;45(3):136-45.
17. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol.* 2004;14(1):13-23.
18. Dalager T, Jensen PT, Eriksen JR, Jakobsen HL, Mogensen O, Sogaard K. Surgeons' posture and muscle strain during laparoscopic and robotic surgery. *Br J Surg.* 2020;107(6):756-66.
19. Cooper H, Lau HM, Mohan H. A systematic review of ergonomic and muscular strain in surgeons comparing robotic to laparoscopic approaches. *J Robot Surg.* 2025;19(1):252.
20. Dalager T, Sogaard K, Bech KT, Mogensen O, Jensen PT. Musculoskeletal pain among surgeons performing minimally invasive surgery: a systematic review. *Surg Endosc.* 2017;31(2):516-26.
21. Alleblas CCJ, de Man AM, van den Haak L, Vierhout ME, Jansen FW, Nieboer TE. Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive Surgery: A Systematic Review. *Ann Surg.* 2017;266(6):905-20.
22. Yang L, Money SR, Morrow MM, Lowndes BR, Weidner TK, Fortune E, et al. Impact of Procedure Type, Case Duration, and Adjunctive Equipment on Surgeon Intraoperative Musculoskeletal Discomfort. *J Am Coll Surg.* 2020;230(4):554-60.
23. Sers R, Forrester S, Zecca M, Ward S, Moss E. The ergonomic impact of patient body mass index on surgeon posture during simulated laparoscopy. *Appl Ergon.* 2021;97:103501.
24. Yang L, Wang T, Weidner TK, Madura JA 2nd, Morrow MM, Hallbeck MS. Intraoperative musculoskeletal discomfort and risk for surgeons during open and laparoscopic surgery. *Surg Endosc.* 2021;35(11):6335-43.
25. Sjøgaard G, Sogaard K, Hansen AF, Østergaard AS, Teljigovic S, Dalager T. Exercise Prescription for the Work-Life Population and Beyond. *J Funct Morphol Kinesiol.* 2023;8(2):73.
26. Arbejdstilsynet. Pas på kroppen i fysisk arbejde [Internet]. København: Arbejdstilsynet; 2025 [cited 2026 Sep 1]. Available from: <https://at.dk/faa-viden/fysisk-arbejde/pas-paa-kroppen-i-fysisk-arbejde/>
27. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: A review of surgical ergonomics literature and development of educational illustrations. *Am J Surg.* 2024;235:115551.
28. Pierce SM, Heiman AJ, Ricci JA. Evaluating the Current State of Ergonomics Education Offered to Students in US Medical Students. *Am Surg.* 2023;89(5):1798-806.
29. Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg.* 2010;210(3):306-13.

30. Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics Workshop Improves Musculoskeletal Symptoms in General Surgery Residents. *J Surg Res.* 2022;280:567-74.
31. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334-59.
32. Winters JN, Sommer NZ, Romanelli MR, Marschik C, Hulcher L, Cutler BJ. Stretching and Strength Training to Improve Postural Ergonomics and Endurance in the Operating Room. *Plast Reconstr Surg Glob Open.* 2020;8(5):e2810.
33. Sjøgaard G, Justesen JB, Murray M, Dalager T, Sjøgaard K. A conceptual model for worksite intelligent physical exercise training - IPET - intervention for decreasing life style health risk indicators among employees: a randomized controlled trial. *BMC Public Health.* 2014;14(1):652.
34. Sjøgaard G, Mann S, Jensen JSD, Oestergaard AS, Dalager T. The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders. *J Electromyogr Kinesiol.* 2021;61:102600.
35. Dalager T, Welch A, O'Leary SP, Johnston V, Sjøgaard G. Clinically Relevant Decreases in Neck/Shoulder Pain Among Office Workers Are Associated With Strength Training Adherence and Exercise Compliance: Explorative Analyses From a Randomized Controlled Trial. *Phys Ther.* 2023;103(2):pzac166.
36. Christiansen HJ, Sandal LF, Mogensen O, Norasi H, Chrouser K, Hallbeck MS, et al. Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA). *Trials.* 2025;26(1):565.
37. Hokenstad ED, Hallbeck MS, Lowndes BR, Morrow MM, Weaver AL, McGree M, et al. Ergonomic Robotic Console Configuration in Gynecologic Surgery: An Interventional Study. *J Minim Invasive Gynecol.* 2021;28(4):850-9.
38. Chrouser K, Kim FJ, Smith A, Stoffel JT, Goldenberg M. Optimizing Outcomes in Urologic Surgery: Intraoperative Environmental, Behavioral, and Performance Considerations. *Urol Pract.* 2020;7(5):405-12.
39. Shahrezaei A, Sohani M, Taherkhani S, Zarghami SY. The impact of surgical simulation and training technologies on general surgery education. *BMC Med Educ.* 2024;24(1):1297.
40. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health.* 1998;52(6):377-84.
41. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Appl Ergon.* 2017;60:334-41.

42. Michie S, van Stralen MM, West R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement Sci.* 2011;6(1):42.
43. Borg GAV. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14(5):377-81.
44. Dalager T, Bredahl TG, Pedersen MT, Boyle E, Andersen LL, Sjøgaard G. Does training frequency and supervision affect compliance, performance and muscular health? A cluster randomized controlled trial. *Man Ther.* 2015;20(5):657-65.
45. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon.* 1987;18(3):233-7.
46. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. *J Clin Nurs.* 2005;14(7):798-804.
47. Ware JE, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Med Care.* 1996;34(3):220-33.
48. Kristensen TS, Borritz M, Villadsen E, Christensen KB. The Copenhagen Burnout Inventory: A new tool for the assessment of burnout. *Work Stress.* 2005;19(3):192-207.
49. Ilmarinen J. The Work Ability Index (WAI). *Occup Med (Lond).* 2007;57(2):160.
50. Grimby G, Börjesson M, Jonsdottir IH, Schnohr P, Thelle DS, Saltin B. The "Saltin-Grimby Physical Activity Level Scale" and its application to health research. *Scand J Med Sci Sports.* 2015;25 Suppl 4:119-25.
51. Strøyer J, Essendrop M, Jensen LD, Warming S, Avlund K, Schibye B. Validity and reliability of self-assessed physical fitness using visual analogue scales. *Percept Mot Skills.* 2007;104(2):519-33.
52. Statens Institut for Folkesundhed. Spørgeskema: Hvordan har du det? 2021 [Internet]. Odense: Syddansk Universitet; 2021 [cited 2026 Sep 1]. Available from: <https://regionsyddanmark.dk/media/yytpvb01/sp%C3%B8rgeskema-sundhedsprofilen-2021.pdf>
53. Dworkin RH, Turk DC, Wyrwich KW, Beaton D, Cleeland CS, Farrar JT, et al. Interpreting the Clinical Importance of Treatment Outcomes in Chronic Pain Clinical Trials: IMMPACT Recommendations. *J Pain.* 2008;9(2):105-21.
54. El Boghdady M, Ewalds-Kvist BM. General surgeons' occupational musculoskeletal injuries: A systematic review. *The Surgeon.* 2024;22(6):322-31.
55. Short C, Basuino M, Segalini N, Rialon KL, Brandt ML. Working Through the Pain: Surgical Culture and Musculoskeletal Injury. *Curr Surg Rep.* 2021;9(7):18.
56. Dorion D, Darveau S. Do micropauses prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. *Ann Surg.* 2013;257(2):256-9.
57. Engelmann C, Schneider M, Kirschbaum C, Grote G, Dingemann J, Schoof S, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: A randomized clinical trial. *Surg Endosc.* 2011;25(4):1245-50.

58. Johnston V, Chen X, Welch A, Sjøgaard G, Comans TA, McStea M, et al. A cluster-randomized trial of workplace ergonomics and neck-specific exercise versus ergonomics and health promotion for office workers to manage neck pain – a secondary outcome analysis. *BMC Musculoskelet Disord.* 2021;22(1):68.
59. Gabrielson AT, Mukherjee A, Alam F, Hallet J. Incorporating ergonomics into surgical checklist workflows. *Am J Surg.* 2025;247:116281.
60. Yazdani A, Wells R. Barriers for implementation of successful change to prevent musculoskeletal disorders and how to systematically address them. *Appl Ergon.* 2018;73:122-40.
61. Graham V, Arora B. Women in surgery: trends in nine surgical specialties. *ANZ J Surg.* 2023;93(10):2344-9.
62. Hislop J, Orth D, Tirosh O, Isaksson M, Hensman C, McCormick J. Does surgeon sex and anthropometry matter for tool usability in traditional laparoscopic surgery? A systematic review and meta-analysis. *Surg Endosc.* 2023;37(9):6640-59.
63. Murray M, Lange B, Nørnberg BR, Sjøgaard K, Sjøgaard G. Self-administered physical exercise training as treatment of neck and shoulder pain among military helicopter pilots and crew: a randomized controlled trial. *BMC Musculoskelet Disord.* 2017;18(1):147.
64. Dalager T, Sjøgaard G, Justesen JB, Steele J. Intelligent Physical Exercise Training in a Workplace Setting Improves Muscle Strength and Musculoskeletal Pain: A Randomized Controlled Trial. *Biomed Res Int.* 2017;2017:1-9.
65. Sundstrup E, Seeberg KGV, Bengtsen E, Andersen LL. A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work. *J Occup Rehabil.* 2020;30(4):588-612.
66. Nielsen SG, Prins JL, Pedersen M, Særvoll CA, Molsted S. Little room for maneuvering: hospital managers' perspectives on integration of physical exercise during working hours. A qualitative investigation in a grounded theory design. *J Public Health.* 2024.
67. Dalager T, Højmark A, Jensen PT, Sjøgaard K, Andersen LN. Using an intervention mapping approach to develop prevention and rehabilitation strategies for musculoskeletal pain among surgeons. *BMC Public Health.* 2019;19(1):320.
68. Bredahl TVG, Særvoll CA, Kirkelund L, Sjøgaard G, Andersen LL. When Intervention Meets Organisation, a Qualitative Study of Motivation and Barriers to Physical Exercise at the Workplace. *ScientificWorldJournal.* 2015;2015:518561.
69. Pultz CJ, Lohse TM, Justesen JB, Særvoll CA, Møller SF, Lindegaard B, et al. Implementation of Intelligent Physical Exercise Training at a Danish Hospital—A Qualitative Study of Employees' Barriers and Facilitators for Participation. *Int J Environ Res Public Health.* 2023;20(22):7085.
70. Andersen LL, Særvoll CA, Mortensen OS, Poulsen OM, Hannerz H, Zebis MK. Effectiveness of small daily amounts of progressive resistance training for frequent neck/shoulder pain: randomised controlled trial. *Pain.* 2011;152(2):440-6.
71. Justesen JB, Sjøgaard K, Dalager T, Christensen JR, Sjøgaard G. The Effect of Intelligent Physical Exercise Training on Sickness Presenteeism and Absenteeism Among Office Workers. *J Occup Environ Med.* 2017;59(10):942-8.

09 Appendix

PhD-afhandlingen *Pain-Free Surgeons*

Pain-Free Surgeons

Development, Launch, and Evaluation of Strategies to
Prevent Musculoskeletal Pain
Among Abdominal and Pelvic Surgeons

PhD dissertation

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Dept. Clinical Medicine 2026

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PREFACE

This thesis was conducted at the Department of Clinical Medicine, Faculty of Health, Aarhus University (AU), in close collaboration with the research unit Physical Activity and Health in Working Life (FAS), Department of Sports Science and Clinical Biomechanics, Faculty of Health Science, University of Southern Denmark (SDU).

With my background in physiotherapy, I came to this project as an outsider to the world of surgeons. My main supervisor, Tina, and co-supervisors, Ole and Pernille (who passed away on 1 February 2026), all took me under their academic wings, and Ole and Pernille introduced me to their department of Gynecology and Obstetrics at Aarhus University Hospital. Pernille introduced me to the operating rooms (ORs) at Aarhus University Hospital (AUH), where I spent several days during the summer and autumn of 2023 gaining first-hand insight into how surgeons work in the OR: their working postures, ergonomic challenges, and the complexity, team-dependence, and hierarchy of surgical work. During that time, I also had informal conversations with surgeons and OR nurses, and their insights helped me develop and launch ERGO.

The project received funding from The Working Environment Research Fund (20215100734) (Arbejdsmiljøforskningsfonden) and the Faculty of Health, AU.

Acknowledgements

Tina, my main supervisor, thank you for opening the door to academia for me and for believing in me from the start. Your support and supervision throughout these four years have meant a great deal. The journey, like most, has had its ups and downs, and your firm guidance when things became overwhelming and your pragmatic approach when the project needed direction and realism have kept me on track. Your extensive knowledge of sports science and eye for detail have sharpened both the science and the writing throughout this work. I also want to thank you for being understanding when life does not always divide neatly into work and leisure, and for never expecting it to.

Ole, you opened the door to the world of surgeons. Thank you for sharing your extensive experience and knowledge of the field of surgery and supervision, and for always believing in this project, even

when things seemed difficult. Your clinical perspective and deep understanding of surgical culture shaped this project, the intervention and the way we approached the field.

To the participating departments, local contact persons, surgeons, and OR staff: As an essential part of my project, I am deeply grateful for your contributions, time, and feedback. Recruiting surgeons to a project like this was not easy, and it became one of the most challenging parts of my PhD journey. I am therefore especially grateful to those of you who took the time to participate, answer questionnaires, attend presentations, and engage with ERGO and IPET in the middle of busy clinical work.

A special thank you goes to my international collaborators, Dr. Susan Hallbeck and her research group at the Mayo Clinic (USA), and Dr. Kristin Chrouser at the University of Michigan, who brought established expertise in surgical ergonomics and operating room interventions. Your contributions to all stages of the project have been invaluable.

Dr. Susan Hallbeck also hosted my research stay at the Mayo Clinic, which was both an honor and a privilege. Experiencing Mayo Clinic as an institution was remarkable in itself - a vast and internationally renowned hospital system that differs profoundly from the Danish healthcare setting in its scale, structure, and culture. And Rochester, a city that in many ways exists because of Mayo Clinic, was a fascinating place to live and work, even briefly.

To my colleagues in the grand office at the Center for Muscle and Joint Health at SDU: you made it a cheerful place to be. Whether during pre-lunch walks, strolls to and from the coffee machine, or conversations in the office, I highly valued your spirit, support, and sincerity. To my colleagues in FAS: you have created a research environment that is both supportive and professionally stimulating. I valued the lively engagement, the chaotic “cowboy feedback” of our meetings, and the clever questions and reflections that inspired and sharpened my thinking throughout. It has been a genuine pleasure to be part of this research unit. A special thank you to Louise for your support at a critical time.

My dear family. Christoffer, thank you for your patience and for understanding how much this meant to me. You stepped up in ways that made all the difference, carrying more than your share at home when I needed it most, and holding space for me when things were hard. Sia and Victor, you may not know it, but your wonderful disruptions and your insistence on my presence pulled me out of the work bubble at exactly the right moments. You reminded me, again and again, of what matters most.

LIST OF PAPERS

The thesis is based on the following papers that will be referred to as papers with their roman numbers.

- I. *Systematic review of applied ergonomics in pelvic and abdominal surgery on surgeon musculoskeletal health.* **Christiansen HJ**, Norasi H, Tetteh E, Hallbeck MS, Chrouser K, Mogensen O, Dalager T. In review at BMJ Open (2025-112046).
- II. *Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA).* **Christiansen HJ**, Sandal LF, Mogensen O, Norasi H, Chrouser K, Hallbeck MS, et al. Trials. 2025;26(1):565. doi:10.1186/s13063-025-09178-x
- III. *Awareness, Practice, and Perceptions Among Abdominal and Pelvic Surgeons Following an Ergonomic Educational Initiative: A Cross-Sectional Study.* **Christiansen HJ**, Mogensen O, Chrouser K, Hallbeck MS, Dalager T. Submitted to Applied Ergonomics (JERG-D-26-00494).
- IV. *Intelligent Physical Exercise Training (IPET) and intraoperative ergonomic recommendations for musculoskeletal pain in surgeons: A Danish multicenter open-label randomized controlled trial.* **Christiansen HJ**, Mogensen O, Gifford S, Li Y, Chrouser K, Hallbeck MS, Dalager T. Manuscript.

DANSK RESUME

Muskelskeletbesvær (MSB) er udbredt blandt kirurger med en rapporteret prævalens på 60-68 % på tværs af specialer. Nakke, skuldre og ryg er de hyppigst ramte kropsdele, og MSB har individuelle, faglige og organisatoriske konsekvenser, herunder nedsat arbejdsevne, ændret operationspraksis og forkortet erhvervsaktiv karriere.

Formålet med denne afhandling var at udvikle, lancere og evaluere strategier til forebyggelse og reduktion af MSB blandt abdominal kirurger, uro- og gynækologer. Det blev gjort ud fra en trinvis tilgang fra evidenssyntese, til interventionsudvikling og -lancering til effekttest.

Studie 1 var et systematisk litteraturstudie, der identificerede 25 studier med ergonomiske interventioner anvendt i praksis, i modsætning til simulation og træningssettings. Ergonomisk uddannelse var oftest forbundet med en reduktion i andelen af kirurger, der rapporterede MSB, mikropauser med reduktion i smerteintensitet og træthed, og optimering af arbejdsstillinger i operationsstuen med forbedringer i biomekaniske målinger. Evidensgrundlaget var begrænset af observationelle, heterogene studiedesigns og beskeden metodologisk kvalitet.

Med afsæt i disse fund blev der i Studie 2, fase 1 udviklet God Ergonomi, som er et sæt ergonomiske anbefalinger med fokus på to komponenter: ergonomiske intraoperative arbejdsstillinger og mikropauser. God Ergonomi blev lanceret på ni danske kirurgiske afdelinger. En tværsnitsundersøgelse 12 uger efter lanceringen viste høj kendskab til begge komponenter, men ulige grad af praksis. Ergonomiske arbejdsstillinger blev praktiseret konsekvent af de fleste kirurger. Mikropauser blev praktiseret mindre regelmæssigt, sandsynligvis fordi mikropauser er teamafhængige og kræver en mere systematisk implementeringsstrategi end individuelle stillingsændringer.

I Studie 2, fase 2 var formålet at undersøge den yderligere effekt af app-leveret Intelligent Motion, en skalerbar og fleksibel løsning, i tillæg til God Ergonomi. Studiedesignet var et randomiseret kontrolleret studie blandt deltagere fra fase 1 (N= 83). Efter 20 ugers intervention var der ingen statistisk signifikant forskel mellem grupperne (Intelligent Motion+God Ergonomi vs. God Ergonomi) i MSB-intensitet. Begge grupper reducerede dog MSB med ca. 1,4-1,7 point på en skala fra 0-10, svarende til et klinisk relevant fald. Lav træningsdeltagelse i Intelligent Motion samt en aktiv sammenligningsgruppe (God Ergonomi) var de mest plausible dele af forklaringen på fraværet af en effektforskel mellem grupperne. Forsøget testede reelt, om app-leveret Intelligent Motion uden

instruktion og supervision, organisatorisk støtte og dedikeret træningstid kunne integreres i kirurgernes dagligdag. Under disse betingelser blev Intelligent Motion ikke leveret i tilstrækkelig dosis til at producere en målbar tillægseffekt på MSB.

Ud fra en teoretisk og forskningsmæssig baggrund fremstår både ergonomisk praksis og målrettet fysisk træning som relevante strategier til at bryde den onde cirkel af belastning og MSB blandt kirurger. Afhandlingens resultat peger imidlertid på, at ingen af dem sandsynligvis er tilstrækkeligt effektive, når de tilbydes som et tillæg til eksisterende kliniske krav uden strukturel forankring og ledelsesmæssig opbakning. Fremtidige interventioner bør integrere fokus på ergonomi og individuel fysisk kapacitet som en fast del af kirurgers grunduddannelse og kliniske onboarding - og rette sig mod hele operationsteamet frem for den enkelte kirurg.

ENGLISH SUMMARY

Musculoskeletal pain (MSP) is a prevalent occupational health problem among surgeons, with reported prevalence estimates of 60-68% across surgical specialties. The neck, shoulders, and back are most commonly affected body regions, and the burden of MSP has individual, professional, and organizational level consequences, including reduced work ability, practice modification, and threats to career longevity and surgical capacity.

This thesis aimed to develop, launch, and evaluate strategies to manage MSP among abdominal and pelvic surgeons, applying a stepped approach from evidence synthesis to intervention development, launch, and effectiveness testing.

Study 1 was a systematic review identifying 25 studies evaluating ergonomic interventions in the operating room (OR). Ergonomic education was most consistently associated with reductions in the proportion of surgeons reporting MSP, microbreaks with reductions in MSP intensity and fatigue, and OR posture optimization with improvements in biomechanical measurements. The evidence base was limited by heterogeneous study designs and modest methodological quality.

Building on these findings, Study 2, Phase 1 translated the review evidence into Good Ergonomics (ERGO), pragmatic ergonomic recommendations with two components: the practice of ergonomic intraoperative working posture and microbreaks. ERGO was launched across nine Danish surgical departments. A cross-sectional survey 12 weeks after launch showed high awareness of both components, but uneven practice. Posture adjustment was practiced consistently by most surgeons, whereas microbreak practice was less consistent, likely reflecting its higher dependence on team support than individual posture adjustments.

In Study 2, Phase 2, the added effectiveness of app-delivered Intelligent Physical Exercise Training (IPET) in addition to ERGO was evaluated in a randomized controlled trial among participants from phase 1 (N= 83). At the primary follow-up at 20 weeks, there was no statistically significant between-group difference in worst MSP intensity. Both groups reduced MSP by approximately 1.4-1.7 points (on a scale from 0-10), which is within the range commonly considered clinically meaningful. Low training adherence and the active nature of the ERGO comparator were the most plausible parts of an explanation for the absence of a between-group effect. The trial ultimately tested whether low-support, app-delivered IPET could be integrated into surgical practice under pragmatic conditions, and found

that without supervision, organizational support, and protected training time, the intervention was not delivered in a sufficient dose to produce a measurable added effect on MSP.

Taken together, from a theoretical and research-based perspective, the findings suggest that ergonomic practice and targeted physical exercise training remain sound strategies for addressing MSP among surgeons. However, neither is likely to be effective when delivered as an add-on to existing clinical demands without structural support. Future interventions should integrate strategies for ergonomic practice and improving surgeons' physical capacity into surgical training and clinical onboarding as standard, and should target the entire OR team rather than the individual surgeon alone.

LIST OF ABBREVIATIONS

APP	Mobile application
AU	Aarhus University
AUH	Aarhus University Hospital
CBI	Copenhagen Burnout Inventory
ERGO	Good Ergonomics (intraoperative ergonomic recommendations)
IPET	Intelligent Physical Exercise Training
ITT	Intention-to-treat
LAP	Laparoscopic surgery
MAYO	Mayo Clinic, Rochester
MSD	Musculoskeletal disorder
MSP	Musculoskeletal pain
NMQ	Nordic Musculoskeletal Questionnaire
NRS	Numerical rating scale
OPEN	Open surgery
OR	Operating room
OUH	Odense University Hospital
RAS	Robot-assisted surgery
RCT	Randomized controlled trial
SAP	Statistical analysis plan
SDU	University of Southern Denmark
SF-12	Short Form 12 Health Survey
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
TIDieR	Template for Intervention Description and Replication
UMICH	University of Michigan
WAI	Work Ability Index
WHO	World Health Organization

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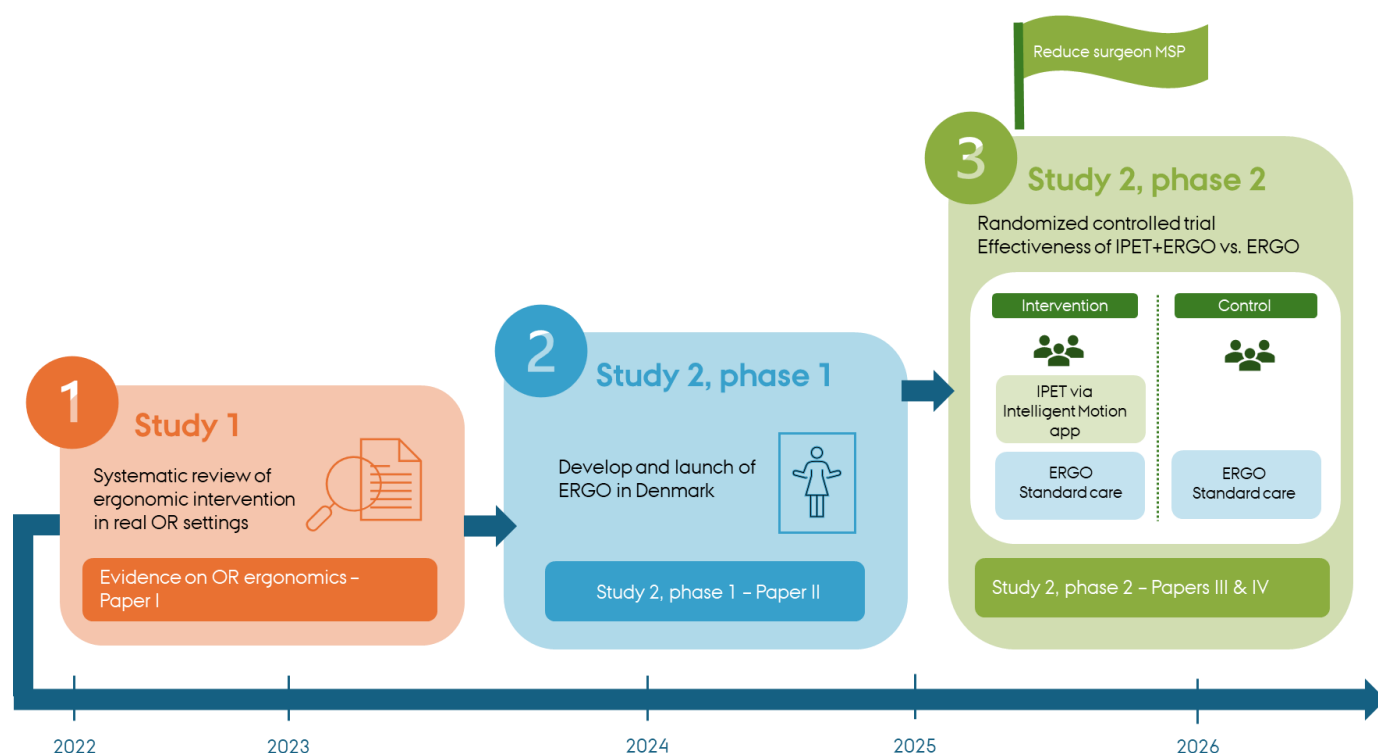
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THESIS AT A GLANCE

This figure illustrates the overall structure of the PhD project. Study 1 provided the evidence-informed foundation by systematically reviewing ergonomic interventions in the operating room. Building on this, Study 2, phase 1 translated the findings into ERGO, launched it at Danish hospital departments, and assessed its uptake in clinical practice. Finally, Study 2, phase 2 evaluated whether adding IPET to ERGO reduced surgeon MSP more than ERGO only in a randomized controlled trial.



BACKGROUND

Musculoskeletal complaints as an occupational health problem

Musculoskeletal disorders (MSDs) are impairments of bodily structures such as muscles, joints, tendons, ligaments, nerves, cartilage, bones and the localized blood circulation system (1). If MSDs are caused or aggravated primarily by work and by the effects of the immediate environment in which work is carried out, they are known as work-related MSDs (2). In the European Union, 60% of workers report MSD complaints, with the back and the upper extremity among the most affected body regions (2). Workers in health care report a higher MSD prevalence than the average European worker (3), and surgeons represent a subgroup with particularly high rates of musculoskeletal pain (MSP). Despite being primarily regarded as a knowledge-intensive profession, the physical demands of surgical work place surgeons among occupational groups with high rates of MSP, comparable to those seen in more traditionally physically demanding occupations (4). Although MSP is a symptom rather than a diagnostic category (5, 6), it is the most common manifestations of MSDs, as musculoskeletal conditions are typically characterized by pain and limitations in mobility and function (1). Therefore, this thesis focuses on MSP, defined as self-reported musculoskeletal ache, pain, or discomfort, rather than clinically diagnosed MSDs.

Surgeons are highly specialized professionals whose training requires many years, making work ability and career longevity important not only for the individual surgeon but also for healthcare capacity (7).

Prevalence and burden of MSP among surgeons

Across surgical specialties, MSP is highly prevalent among surgeons. One meta-analysis reported 12-month prevalence estimates of 60% for neck MSP, 52% for shoulders, and 49% for the back (4).

Another review and meta-analysis reported an overall MSP prevalence estimate of 68% across mixed surgical specialties (8). Taken together, these reviews indicate that MSP is not confined to one surgical field but represents a broader occupational health problem in surgery. The body regions most affected are typically the neck, shoulders, and back (4), and often affect several body regions simultaneously referred to as multisite pain (9-11).

The high prevalence of MSP has consequences at individual, professional and clinical levels. At the individual level, MSP may affect surgeons' broader wellbeing, and a survey among Danish abdominal and pelvic surgeons reported that MSP negatively affects work, leisure time activities, and sleep (9), and is associated with risk of burnout (12, 13). Beyond individual wellbeing, the presence of multisite MSP has been associated with poor work ability among health care workers (14).

At the professional level, MSP may threaten work ability (14, 15) and career longevity (16, 17). Among mixed-specialty surgeons with MSP, a meta-analysis estimated that 12% require a leave of absence, practice restriction or modification, or early retirement (4). At the clinical and organizational level, MSP has consequences for surgical work, as surgeons perceive MSP and fatigue to be performance-limiting during surgery (12, 18-22), which may affect the quality of care. Indirectly, surgeon MSP may also affect surgical capacity when surgeons reduce their caseload to cope with MSP or take time off due to sickness absence (20, 22, 23). Thus, surgeon MSP should not only be understood as an individual health problem, but also as a professional and organizational issue. This burden of MSP reflects, in part, the specific physical demands surgeons are exposed to during surgical work.

Although MSP is multifactorial and shaped by biological, psychological, and social factors, this thesis focus primarily on the physical dimension as this provides a practical framework for understanding how the fit between surgical work and the surgeon may be improved (24, 25).

Physical work demands and individual capacity

Surgical work involves specific physical work demands that may increase the risk of MSP (3). These demands include prolonged static postures, awkward positions, repetitive movements, high precision demands, and limited opportunities for muscular rest during procedures (26, 27), all of which may contribute to MSP because they often require low-level but sustained muscle activity over prolonged periods (28). Unlike dynamic physical work, static loading provides limited variation and fewer opportunities for muscle recovery, which may contribute to local fatigue and eventually MSP (29, 30). Thus, even when the absolute force demands are low, the relative and cumulative load may be substantial (28, 29).

The specific physical demands vary by surgical modality, as each modality imposes distinct ergonomic demands. In open surgery (OPEN), the surgeon has direct visualization of the operative field, but this

often involves prolonged standing and neck flexion, which may be exacerbated by the use of loupes (27). Laparoscopic surgery (LAP) imposes demands related to reduced dexterity and tactile and haptic feedback, two-dimensional visualization, and instrument handling through fixed trocar positions (17, 27, 31, 32). In RAS, the surgeon is seated at the console which may reduce demands compared to standing, but can introduce other demanding postures such as elevated shoulders and static lower back strain, and high forearm muscle activity when operating the robot joysticks. These biomechanical demands are illustrated in Figure 1A-D.

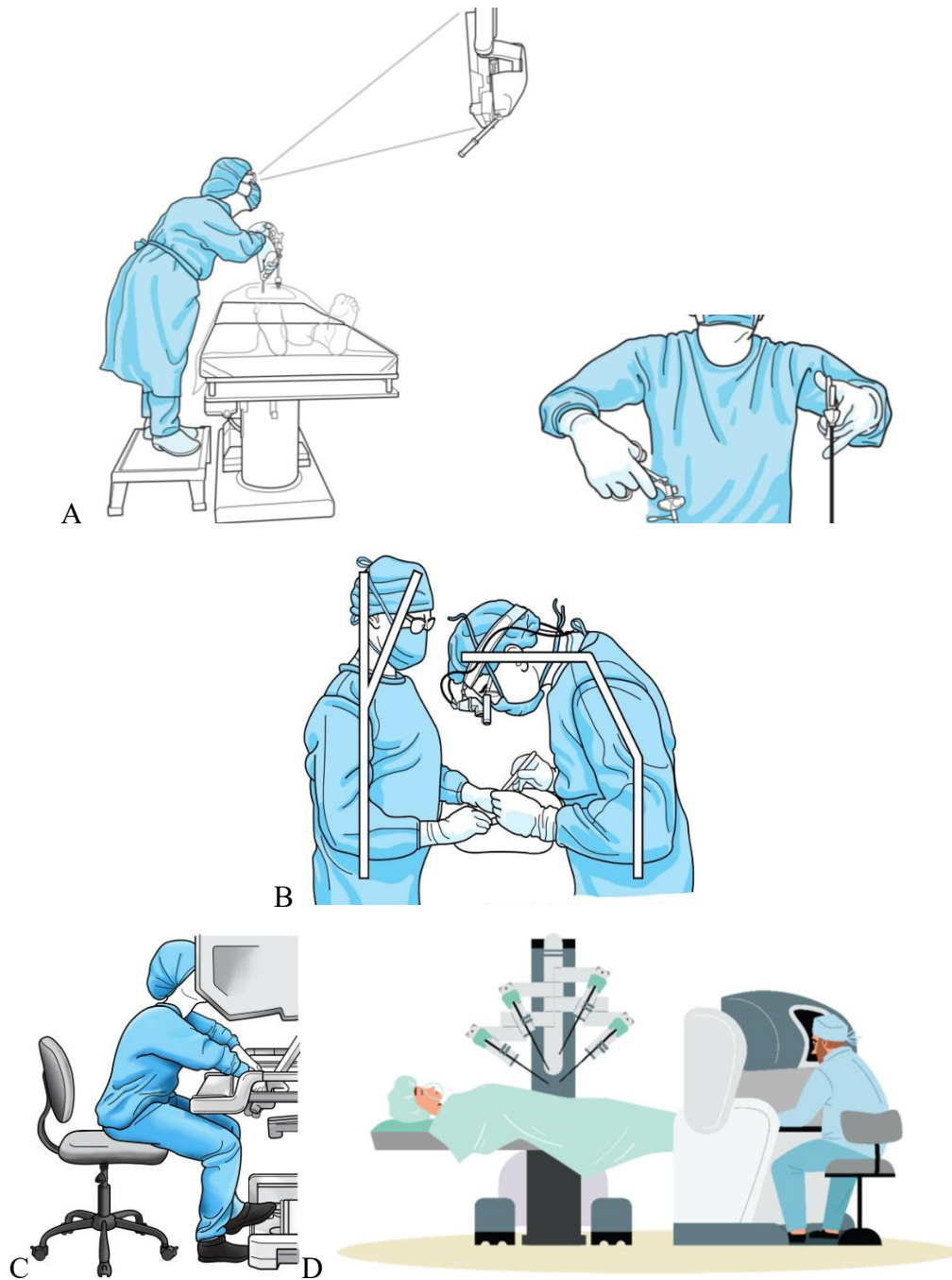


Figure 1 Examples of modality-specific working postures in abdominal and pelvic surgery. A: LAP, B: OPEN, C-D: RAS.

Although MSP prevalence has been reported to be higher in LAP and RAS than in OPEN (8), and higher in LAP than in robot-assisted surgery (RAS) (19, 33), no modality should be considered

protective of MSP, because surgical modalities may instead shift rather than remove physical demands between different body regions (26, 32, 34).

The duration and complexity of surgical work may also influence MSP. Higher caseload (19), longer case duration (11), and operating on patients with higher BMI have been associated with MSP (35). These factors may increase the physical demands by prolonging the time surgeons spend in constrained working postures and by increasing the physical effort required during surgery. Thus, MSP is likely influenced not only by the posture itself, but also by the duration and context in which high-risk postures are maintained. Poor OR working posture and time spent in high-risk postures have both been associated with MSP (36, 37).

Abdominal and pelvic surgeons in gynecology, urology and colorectal surgery share several surgical modalities, including OPEN, LAP and RAS, and therefore face similar ergonomic challenges. Therefore, this thesis focuses mainly on these specialties to address a relatively coherent surgical population while still covering variation in surgical modality and OR working postures.

The same external work demands may be experienced differently depending on the surgeon's physical capacity, recovery, and individual characteristics. Thus, the physical demands of surgery may represent a higher relative load for surgeons with lower physical capacity, or a less favorable anthropometric fit with instruments or OR layout. Some of these characteristics are non-modifiable, including sex, age, and anthropometry, whereas others, such as fitness and muscle strength, are modifiable. Women in surgery have approximately twice the odds of reporting MSP compared to male colleagues (38), likely reflecting a combination of anthropometric mismatch and lower relative physical capacity rather than anthropometry alone (39, 40).

Evidence on the association between age and MSP is less consistent (19), suggesting that age alone does not explain MSP development, possibly because of the "healthy worker effect" (30), whereas MSP development is more likely related to cumulative exposure, physical capacity, and recovery. Surgeons who report regular physical activity and greater grip strength appear to have a lower risk of MSP (15, 41, 42). Thus, physical capacity and fitness may represent modifiable factors that influence how well surgeons tolerate the physical demands of surgical work. Together with the work demands described above, these individual factors form the basis for understanding surgeon MSP as a balance between external demands and individual capacity.

Understanding surgeon MSP: the demand-capacity balance

Within the physical dimension, surgeon MSP can be understood as a potential mismatch between external work demands and the surgeon's individual physical capacity. External work demands are determined by the physical work environment, surgical modality, case duration, patient-related factors, and time and constrained OR working postures. Individual physical capacity is shaped by factors such as sex, age, anthropometry, muscle strength, fitness, and recovery.

One way to understand MSP development within this physical dimension is through the balance between work demands and individual physical capacity, as illustrated by the virtuous and vicious circle in Figure 2: When the physical demands of surgical work are within the surgeon's capacity, the risk of MSP is lower. This corresponds to the virtuous circle described in the model (43). However, if the work demands are higher than the surgeon's physical capacity, the relative load becomes too high, and the surgeon is at higher risk of muscular fatigue, MSP, reduced function, and over time, chronic MSP and wear and tear. This corresponds to the vicious circle.

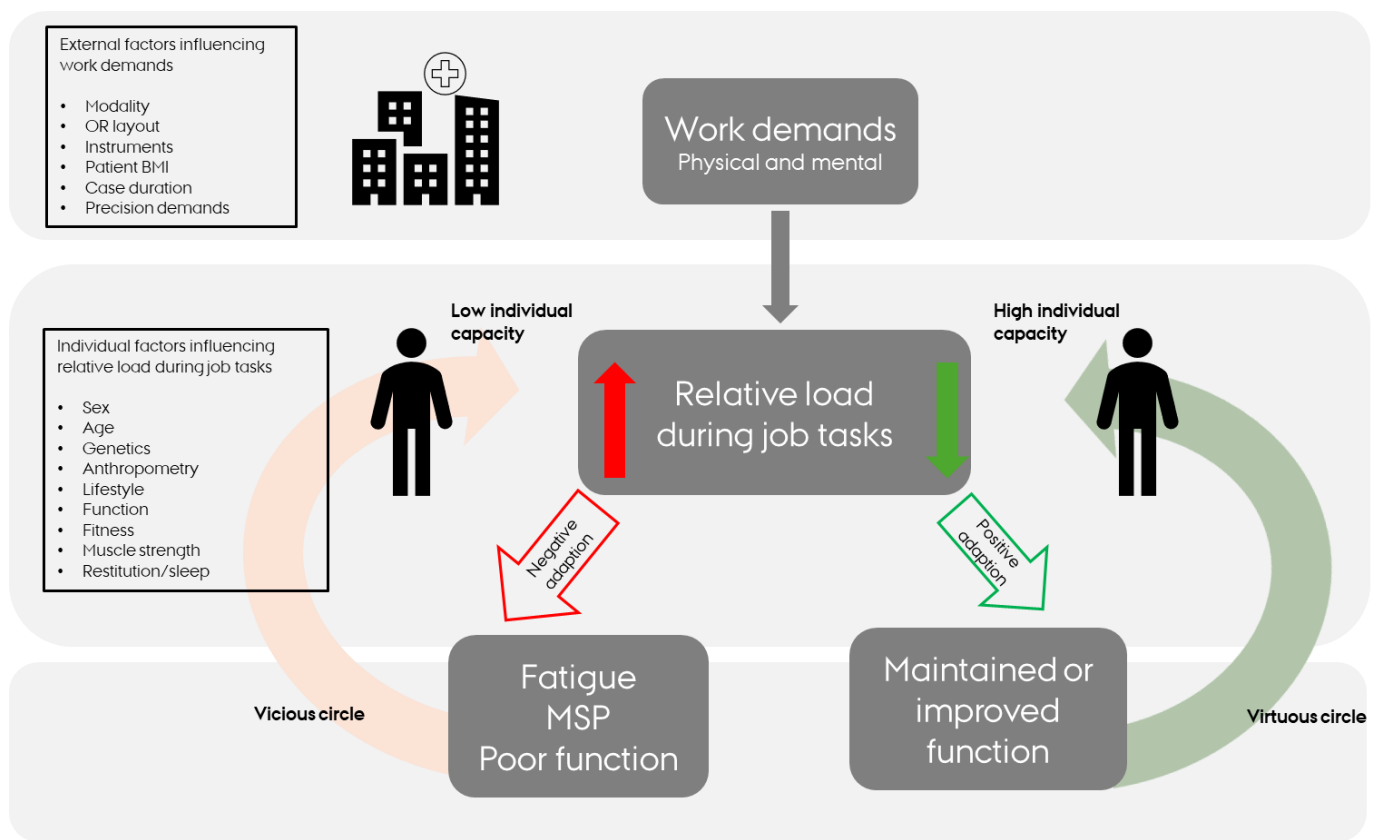


Figure 2 External and individual factors influencing the virtuous and vicious circle (43)

Figure 3 illustrates the importance of this rationale across working life. As we age, our physical capacity declines. In many jobs, the physical work demands remain the same, which may become critical when work demands exceed individual capacity. The red dashed line represents the physical work demands of surgical work, while the green curves represent physical capacity. When the dark green capacity curve falls below the red work-demand line, the relative workload increases, and the risk of fatigue, reduced function, and MSP may increase. Ergonomic strategies, represented by the red dashed line, may lower the physical demands of surgical work, whereas tailored physical exercise training, represented by the lighter green curve, increases or maintains surgeons' physical capacity and thereby helps avoid or postpone the critical state.

Reducing physical demands and increasing physical capacity are the two complementary intervention targets, and the rationale for combining them is addressed further in the following sections.

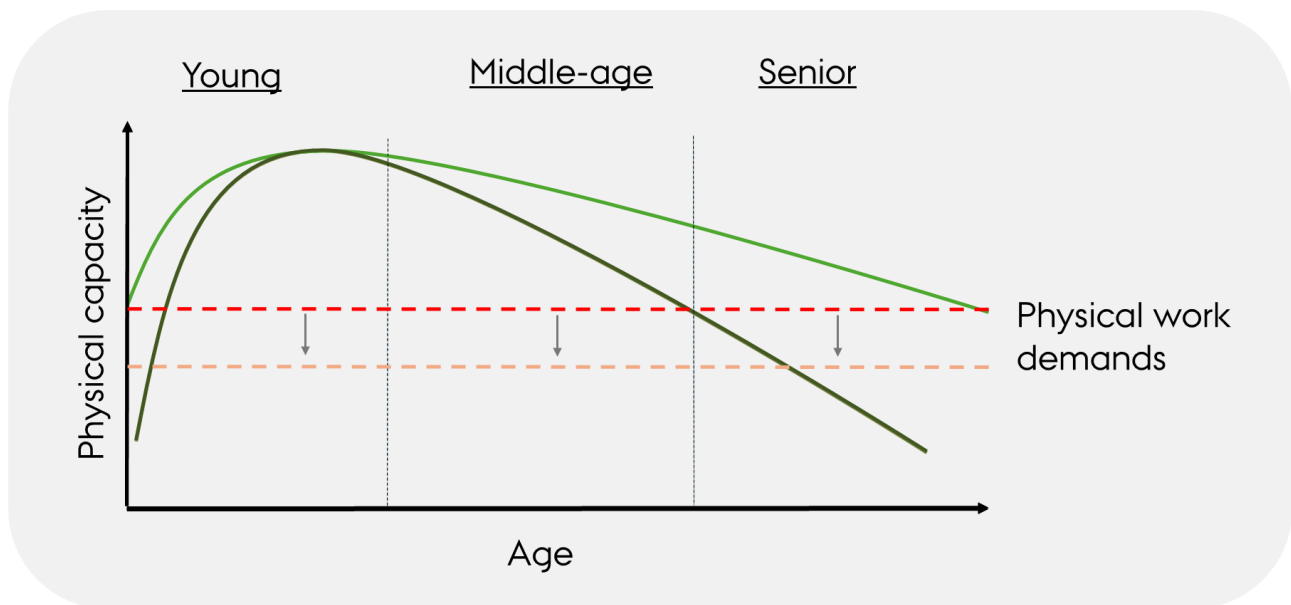


Figure 3 Physical capacity and physical work demand across the working life

Fitting the OR to the surgeon

Ergonomics is the discipline concerned with designing work systems and environments to suit human needs, thereby improving comfort, safety, and performance (44). It encompasses three main domains:

cognitive, organizational, and physical ergonomics. Cognitive ergonomics concerns mental workload and stress responses during high-stakes tasks, while organizational ergonomics addresses workflow design, team coordination, and scheduling. The physical ergonomics in the OR addresses risk factors in the OR such as awkward working postures, repetitive movements, twisting, and forward bending (44-46) which are all inherent to surgical practice (47). In the OR, this may include adjustment of monitor position and table height, surgeon positioning, instrument handling, and incorporating opportunities for brief muscular recovery.

Despite the relevance of surgical ergonomics, surgeons report limited formal training, and surgical ergonomics is rarely incorporated into residency curricula (48, 49). Some institutions, primarily in the United States, have begun to address this gap through surgical ergonomics education and training initiatives (50, 51). However, overall awareness of ergonomic recommendations and guidelines among surgeons also remains limited (4, 27). This matters because surgeons often perceive their OR posture as a cause of MSP (52), yet without sufficient ergonomic knowledge they may lack the tools to recognize or modify harmful loading patterns before symptoms develop, and higher ergonomic awareness has been associated with more frequent ergonomic practice (53). Although surgical ergonomics is increasingly recommended as a MSP management strategy, it remains unclear which specific ergonomic interventions have been evaluated in real OR settings and whether they improve surgeons' musculoskeletal health.

Fitting the surgeon to the OR

Paradoxically, physical activity may be both part of the problem and part of the solution to MSP (28). This distinction is important because occupational physical activity often involves prolonged static loading, awkward postures, repetitive movements, or insufficient recovery (3, 30, 54). While tiring, the intensity is insufficient to induce positive physiological adaptation (28). In contrast, leisure-time physical exercise training is structured, progressive and often of shorter duration but higher intensity, which is necessary for improving muscle strength, endurance, and cardiorespiratory fitness. For exercise to have a health-enhancing and pain-reducing effect, it should be sufficiently intensive, specific to the relevant body regions, tailored to the individual's general capacity and symptoms, and with sufficient recover afterwards (55, 56).

The second approach to MSP management is to increase the surgeon's physical capacity, thereby improving the ability to tolerate the physical demands of surgical work by lowering the relative load. Although physical exercise training is well established in sports science, rehabilitation and occupational health (43, 57, 58), it has received less attention as a strategy to sustain surgeons' musculoskeletal health and career longevity, but the topic is receiving increasing attention (52, 59-61). Despite growing interest, it remains unclear whether physical exercise training can reduce MSP among surgeons, and whether it adds benefit when combined with ergonomic strategies.

Intelligent Physical Exercise Training

One approach that operationalizes this tailored exercise prescription is Intelligent Physical Exercise Training (IPET). IPET is an evidence-based approach to exercise prescription for the working populations and targets the capacity side of the demand-capacity balance (56). The concept entails 50 minutes training per week and tailor a combination of aerobic, strength, functionally and balance training to each individual (56). IPET has been evaluated in more than 17 randomized controlled trials, involving over 4,000 workers, mainly in Denmark. Across occupational groups, IPET has shown beneficial effects on MSP, strength, cardiovascular fitness and work-related health outcomes (29, 43, 62).

Across mixed worker populations, including both workers with and without MSP at baseline, average pain intensity was generally reduced modestly, from approximately 3 to approximately 2 on a 0-9 numerical rating scale (NRS). However, larger effects were observed among workers classified as pain cases, defined as baseline MSP intensity of ≥ 3 (63). In these groups, MSP intensity decreased from approximately 5 to below 3, corresponding to a clinically relevant reduction (64). Importantly, the magnitude of pain reduction appears to be related to training volume, suggesting a dose-response relationship between adherence to IPET and pain reduction (29, 65, 66).

IPET is particularly relevant in the context of surgeon MSP because it is tailored to the individual's occupational exposure, physical capacity, health indicators, and painful body regions. This makes IPET conceptually aligned with the capacity side of the demand-capacity balance and practically relevant for surgeons, whose MSP is often multisite. In contrast to general advice to be physically active, which is less effective for MSP (55), IPET provides a structured and individualized exercise "prescription" in the right dose.

Despite evidence from other occupational groups, it remains unclear whether IPET is feasible and effective among surgeons. Surgeons represent a distinct occupational group because their work is organized around operating lists, acute clinical demands, patient care, and limited control over daily schedules. Whether IPET specifically is feasible and effective in this occupational group therefore remains to be established.

AIM AND OBJECTIVES

The aim of this thesis was to develop, launch and evaluate strategies to prevent and reduce MSP among abdominal and pelvic surgeons.

A systematic review (Paper I) was conducted to establish an evidence-informed ergonomic foundation, followed by a two-phase RCT in which Good Ergonomics (ERGO) was launched as standard care (Phase 1; Paper II) before testing the primary effectiveness question of the RCT: whether adding IPET to ERGO reduced MSP more than ERGO only (Phase 2; Papers III–IV). This was operationalized through the following objectives:

- Objective 1: To systematically review and synthesize evidence on ergonomic interventions applied within the OR setting and their effects on abdominal and pelvic surgeons' musculoskeletal health (Paper I).
- Objective 2: To translate the review findings into evidence-informed, feasible ergonomic recommendations (ERGO); to develop and launch ERGO across Danish surgical departments; and to assess surgeons' awareness and practice of ERGO (Phase 1, Paper II).
- Objective 3: To investigate the added effectiveness of IPET in addition to ERGO, compared to ERGO only, for reducing MSP among abdominal and pelvic surgeons in a RCT (Phase 2, Papers III and IV).

INTERNATIONAL COLLABORATION

This thesis was developed through international collaboration with Dr. Susan Hallbeck's research group at the Mayo Clinic (USA) and Dr. Kristin Chrouser at the University of Michigan, both of which have established expertise in surgical ergonomics and OR interventions. Both collaborators contributed to the design of the ERGO intervention and the RCT, supported recruitment at North American sites, and provided critical input on intervention content, and manuscript preparation. They are co-authors on all subsequent papers in this thesis.

STUDY PARTICIPANTS

The population of interest in this thesis is abdominal and pelvic surgeons, including colorectal surgeons, urologists, gynecologists, and general surgeons, depending on local organization structure. This population was selected because their surgical modalities, working conditions, and working postures are broadly comparable, meaning that ergonomic recommendations are likely to overlap across specialties. Building on previous work (9) and to maintain a relatively homogeneous target group, ERGO was specifically designed for these specialties, addressing OPEN, LAP and RAS approaches.

METHODS STUDY 1

Study 1 comprised a systematic review of ergonomic interventions delivered in the OR, with evidence synthesized by intervention type and reported effects on musculoskeletal health and workload. The review served two purposes: to identify effective ergonomic interventions among abdominal and pelvic surgeons, and to provide an evidence-informed basis for the development of the ERGO recommendations. A key methodological decision was to exclude simulation-based evidence, on the grounds that the demands of live surgery differ substantially from those of controlled or training environments (67, 68). Other methodological aspects and their implications for the subsequent study, are described below; for full detail, see Paper I – Systematic review.

Eligibility Criteria

Eligible studies had to fulfil certain criteria related to participants, intervention, outcomes and study design. These are described below and summarized in Table 1.

Studies with mixed surgical specialties were included only if all other eligibility criteria were met, which in practice resulted in the inclusion of some studies where a considerable proportion of participants performed surgery outside the abdominal and pelvic specialties.

The inclusion was restricted to ergonomic interventions applied in real OR settings, as interventions evaluated in simulation or training environments were considered unlikely to reflect the demands of actual surgical work (67, 68).

Ergonomic education was included as an eligible intervention type, but only where the educational content was explicitly intended to be applied by surgeons during surgery.

Outcomes were defined broadly to include both subjective, objective, and observer-based measures of musculoskeletal health and physical workload, given the heterogeneity expected in this literature. Study designs were eligible if incorporating outcome assessments before and after the intervention. RCT evidence in this field was expected to be sparse and a broader scope was needed to map the range of interventions applied under real OR conditions.

Table 1 Overview of key study eligibility criteria

Component	Inclusion criteria	Exclusion criteria
Intervention	Ergonomic interventions or initiatives applied during live surgery, including ergonomic education intended for intraoperative application.	Studies conducted in simulation or training environments.
Outcomes	Self-reported, observer-based or objectively measured outcomes	Studies reporting only performance-related outcomes (e.g. surgical precision), or patient-related outcomes (e.g. blood loss).
Participants	Surgeons performing abdominal or pelvic surgery, including gynecology, urology, colorectal, and general abdominal surgery. Studies with mixed surgical specialties were included only if all other eligibility criteria were met. Surgical approaches included conventional laparoscopy, robot-assisted laparoscopy, open surgery, or a combination.	Studies with only endoscopy, vaginal access (natural orifice), microsurgery.
Study design	Any design incorporating outcome assessments before and after an ergonomic intervention, at the group or individual level, including experimental and observational studies. No restrictions were applied regarding sample size, follow-up duration, or blinding	Reviews, editorials, conference abstracts, case reports, and qualitative studies. Studies published in languages other than English.

Search strategy

The literature search was performed in three databases: Medline, Embase and Cochrane Central Register of Controlled Trials (CENTRAL), from database inception to July 2022, with an updated performed in July 2024. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords covering surgical ergonomics and OR settings and was developed with input from a research librarian specializing in work physiology. An example of the search strategy is provided in Table 2; the strategy was adapted for each database. Systematic and narrative reviews identified during screening but not eligible for inclusion were reviewed for additional relevant references.

Table 2 Example search strategy (Embase (Ovid))

Ergonomic Intervention / Initiative*	Population / Setting / Modality*
(Ergonom* adj3 (intervention* or modification* or assessment* or program*)) OR (Standing/ or Erect posture/ or Body position/ or (body position* or work* posture* or work* position*) adj5 (Surgeons/ or surgeon*)) OR ((Ergonomic adj3 (chair or seat or posture or tool or instrument or design)) OR ((Floor adj mat) or (foot adj pedal) or (body adj support) or (bed adj height) or ((operating theat* or room) adj design) or (microbreak* or micropause or intraoperative break*)) OR ((industrial or human factors) adj2 engineering) OR (Occupational Health/ or ((occupational or employee) adj2 health)) OR Ergonomics/ or ergonomic*	(General surgery/ or general adj surger*) OR (Urology/ or urology) OR (Urologic surgery/ or urologic adj surger*) OR (Urologist/ or urologist) OR (Gynecologist/ or Gynecology/ or gynecolog*) OR (GYNECOLOGIC surgery/ or gynecologic adj surger*) OR (Gastrointestinal surgery/ or gastrointestinal adj surger*) OR (Colorectal surgery/ or colorectal adj surger*) OR Abdominal surgery/ or abdominal adj surger*) OR ((General or Urolog* or urogenital or liver* or Gynecolog* or gynaecolog* or hepatobiliary or gastric or Abdom* or Colorectal or pelvic) Adj2 (Surgeon/ or surgeon* or surgical)) OR (Operating rooms/ or (surg* or operati*) adj1 (room or theat*)) OR (Open surgery/ or Laparoscopy/ or Robot assisted surgery/ or ((open or laparoscop* or robot*) adj (surger* or procedure*)))

*Searched in title, abstract and keywords

Screening, selection and data extraction

The literature search results were managed using Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Screening of title and abstract was independently conducted by two reviewers and followed the eligibility criteria listed. The full-text screening followed the same approach. In cases of disagreement, a third reviewer was consulted to reach consensus. Reasons for excluding studies were documented throughout the process. None of the review authors were blinded to journal titles, study authors, or institutions.

Data extracted included information on study characteristics, intervention content and comparator conditions, outcome measures, measurement tools, and findings related to musculoskeletal health and physical workload. The extraction of data was conducted in Covidence, and the structure template used is shown in Table 3. Three reviewers extracted data, and two other reviewers verified it, and discussed any disagreements.

Table 3 Data extraction template used to synthesize ergonomic intervention content and outcomes

Domain	Extracted information
Study characteristics	Author, year, country, number of participants, surgical specialty, surgical modality, study type, and study design
Intervention and comparator	Description of intervention and comparison conditions, including components, delivery, dose, timing, frequency, duration, implementation requirements, integrity/fidelity, co-interventions, and control definition
Outcomes	Primary and secondary outcomes, specific metrics, method of aggregation, timing of outcome assessment, and adverse effects
Measurement tools	Instruments used to assess musculoskeletal health or workload, and direction of favorable scoring where relevant
Results	Findings related to musculoskeletal health and workload, including measures that favored the intervention, showed no clear effect, or were mixed.

Assessment of methodological quality

Critical appraisal was conducted using the Downs and Black checklist (D&B) (69). It was selected because it supports appraisal across both randomized and non-randomized studies, making it suitable for a mixed-design review. Each of the 27 checklist questions is scored from zero to two points, resulting in a maximum total of 28 for RCTs and 25 for non-randomized studies. Higher total scores reflect a lower risk of bias, and studies were classified as excellent (26–28), good (20–25), fair (15–19), and poor (≤ 14) (70–72). The appraisal of included studies was done in duplicate pairs, and disagreements were resolved by discussion.

The GRADE approach was not applied, as the substantial heterogeneity in outcome definitions and measurement methods across included studies did not allow for meaningful assessment of the certainty of evidence at the outcome level. All studies were included regardless of methodological quality to allow a broader synthesis of the available evidence.

Narrative synthesis approach

Studies were grouped according to their primary intervention component, and a narrative synthesis was conducted. This approach was chosen because of the substantial heterogeneity in study designs, outcome definitions, and measurement methods. In studies that included overlapping elements, which was common among ergonomic education studies that also addressed posture and microbreaks, categorization was based on the predominant component. This overlap should be considered when interpreting findings across categories. Findings were reported according to whether they suggested potential benefit, showed no clear association, or were inconsistent across outcomes or body regions, thereby providing a balanced interpretation of the evidence.

RESULTS STUDY 1

Main findings

The literature search across the three databases yielded 25 eligible studies. The flow from search to inclusion is presented in Figure 4. With one exception, all studies were observational, including seven pilot studies and two feasibility studies. Overall methodological quality was rated as fair. There was substantial heterogeneity across designs, populations, and methods. Sample sizes varied, ranging from single-surgeon assessments to 141 participants. The studies were conducted across North America ($n = 10$), Europe ($n = 9$), and Asia ($n = 6$). The narrative synthesis resulted in five overarching categories based on their primary intervention component: ergonomic education, microbreaks, OR posture optimization, body support devices, and miscellaneous ergonomic devices. Key study characteristics are presented in Table 4.

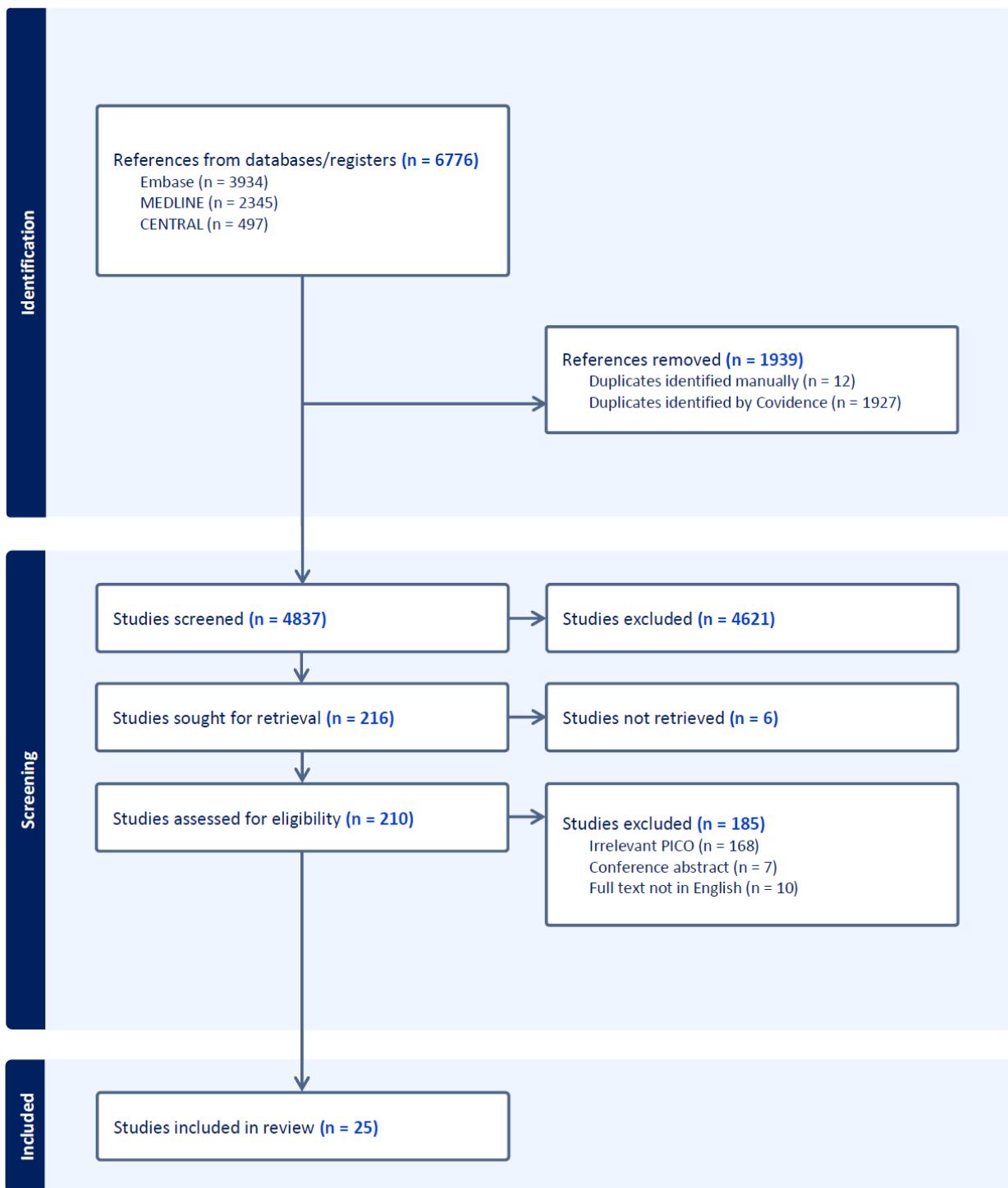


Figure 4 Flowchart from literature search to inclusion

Table 4 Characteristics of included studies

Intervention type	Author	Year	Study design	Sample size	Surgical specialty	D&B category
Ergonomic Education	Allespach	2020	Pre-post pilot study	n= 36 at baseline, n= 18 after module 1-2, n= 15 after module 3	General	Poor
	Cerier	2022	Pre-post study	n= 33 pre-workshop, n= 22 after workshop, n= 22 post-workshop	General	Fair
	Franasiak	2014	Pre-post feasibility study	n= 42 at baseline n= 32 received personalized session, n= 37 post-intervention	Combination	Fair
	Giagio	2019	Cluster randomized controlled trial	n= 141	Combination	Good
	Hess	2024	Pilot case-crossover	n= 6	General	Fair
	Yadav	2023	Pre-post study	n= 71 at baseline, n= 46 post-webinar, n= 34 at 2-month post-webinar	General	Fair
Microbreaks	Dorion	2013	Case-crossover	n= 16	Combination	Poor
	Engelmann	2011	Case-crossover	n= 7	General	Fair
	Hallbeck	2017	Case-crossover	n= 56	Combination	Fair
	Kromberg	2020	Case-crossover	n= 12	General	Good
OR posture optimization	Chan	2024	Pre-post study	Phase 1: n= 46 Phase 2: n= 64	General	Fair
	Hokenstad	2021	Pilot case-crossover	n= 6	Gynecology	Fair
	Klein	2010	Case-crossover	n= 10	General	Fair
	Lim	2022	Case-crossover	n= 3	Combination	Fair
	vanDet	2008	Case-crossover	n= 32	General	Fair
	Veelen	2002	Case-crossover	n= 12	General	Fair
Body support devices	Cha	2024	Pilot case-crossover	n= 7	General	Fair
	Kawahira	2021	Pilot case-crossover	n= 3	General	Poor
	Liu	2018	Case-crossover feasibility	n= 7	General	Fair
	Nishimoto	2019	Case-crossover	n= 5	Colorectal	Fair
Misc. Ergonomic Devices	Dalager	2019	Pilot case-crossover	n= 6	Gynecology	Fair
	Haramis	2010	Case-crossover	n= 18	Urology	Fair
	Kraemer	2018	Pilot case-crossover	n= 11	Gynecology	Fair
	Rassweiler	2012	Comparative study	n= 1	Urology	Poor
	Unver	2023	Case-crossover	n= 38	Combination	Good

D&B = Downs and Black checklist; n = number of participants or observations included at the specified assessment point. Pre-post studies assessed outcomes before and after an intervention without a separate control group. Case-crossover studies compared intervention and control conditions within the same participants. Where several sample sizes are reported, these reflect the available sample at baseline, intervention exposure, and/or follow-up.

Table 5 summarizes Study 1 findings at the intervention-type level and provides an overview of the direction of findings across the included studies. The relative size of the figures in the Outcome type column indicates which outcome types dominated the evidence within each intervention category.

Because of heterogeneity in study design, intervention content, outcome definitions, and measurement tools, the table should be interpreted as an evidence map.

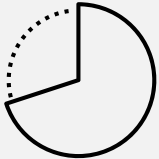
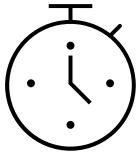
Six studies focused on ergonomic education (18, 51, 73-76), which were associated with a reduction in the proportion experiencing MSP. Several studies included overlapping intervention elements, e.g. guidance on working posture and the use of microbreaks (18, 51, 76).

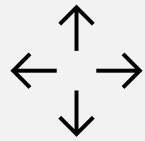
Another four studies explored the impact of intra-operative microbreaks, with or without stretching exercises (16, 77-79), which were associated with reduction in absolute MSP intensity and fatigue. Six studies investigated OR posture optimization (80-85), which were associated with improved posture /biomechanics. Four studies investigated the impact of body support devices (86-89), with no consistent associations across outcome domains. Five studies investigated miscellaneous ergonomic devices (90-94), which were heterogeneous and not directly comparable, although two anti-fatigue mat studies were associated with reduced MSP intensity and fatigue.

Methodological quality

The methodological quality was overall rated as fair. Three studies were rated as "good" (score 20–25) 18 studies were rated as "fair" (score 15–19), four studies were rated as "poor" (score ≤ 14). This was mainly due to small sample sizes, incomplete reporting of selection and recruitment procedures (all, except (16, 73, 90)), limited participant characteristics (18, 77-81, 85, 88), and lack of sample size or power calculations (all, except (73, 77, 85)).

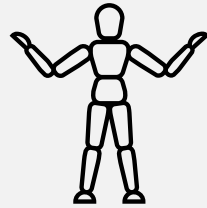
Table 5 Evidence map of ergonomic intervention types identified in Study 1

Intervention type (no. of studies)	Main intervention content	Outcome type (measurement methods)	Results in favor of intervention	Results not in favor / mixed	D&B category / evidence strength
 Ergonomic education (n= 6) (18, 51, 73-76)	Lectures, workshops, webinars, coaching, and training in ergonomic principles.	 MSP proportion (self-reported) ↓ MSP absolute intensity (self-reported)  Posture/biomechanics (observer-based)	Most studies reported reductions in the proportion of participants with MSP. One cluster-RCT reported a lower proportion of low-back pain in the intervention group. One study reported reduced MSP intensity. One study reported improved postural risk scores (RULA).	No consistent reduction in MSP proportion across body regions, MSP intensity not consistently reduced. Interpretation Effects were difficult to isolate because education was often combined with other components.	Fair (median D&B 15.5); one good-quality RCT.
 Microbreaks (n= 4) (16, 77-79)	Short intraoperative breaks ± stretching, 10 seconds to 5 minutes, every 10-40 minute.	↓ MSP absolute intensity (self-reported)  Muscle activity/fatigue (self-reported and objectively measured)	Absolute MSP intensity reduced in the upper body in three studies. Self-reported muscular fatigue reduced in two, and in one with an objective test (straight-arm test).	One study found no significant effect of 10-sec microbreaks on absolute MSP intensity, self-reported fatigue, or objectively measured muscular fatigue (straight-arm test). Effects on MSP varied by body region across studies.	Fair (median D&B 19); all were case-crossover studies.



OR posture optimization (n= 6)
(80-85)

Optimization of OR posture by adjusting OR setup; including monitor position, robotic console settings, using visual aids.



Posture/biomechanics
(self-reported, observer-based, objectively measured)

Posture improved in four studies: self-reported ergonomic quality improved in two, and observer-based postural risk scores reduced in two (REBA, IMU), and objectively measured neck angles improved in three (IMU, video). Absolute MSP intensity reduced in three studies. Objectively measured muscular fatigue reduced in two studies (EMG).

Posture improvements differed by surgeon role and body region across studies; no consistent reduction in self-reported MSP intensity. One study found no reduction in MSP proportion (pre-post comparability uncertain).

Fair (median D&B 16.5); mostly case-crossover studies.



MSP absolute intensity
(self-reported)



Muscle activity/fatigue
(self-reported, objectively measured)



Body support devices (n= 4)
(86-89)

Arm-support exoskeletons, lower-limb support devices.



Posture/biomechanics
(objectively measured)

Reduced time in objectively measured demanding shoulder postures (IMU). Reduced objectively measured muscle activation in selected muscles in two studies (EMG). One study reported reduced absolute MSP intensity in the shoulders.

Findings differed by device type; effects were inconsistent across muscles and sides of the body (EMG). Three of four studies found no reduction in absolute MSP intensity. Lower-limb support devices showed no significant reduction in muscle activity (EMG).

Fair (median D&B 15.5); pilot/feasibility studies.



Muscle activity/fatigue
(self-reported, objectively measured)



MSP absolute intensity
(self-reported)



**Miscellaneous
ergonomic devices**

(n= 5)
(90-94)

Anti-fatigue mats,
ergonomic OR
chairs, rotatable
laparoscopic
handle.

↓
MSP absolute intensity
(self-reported)



Muscle activity/fatigue
(self-reported,
objectively measured)



Posture/biomechanics
(observer-based)

Two studies of anti-fatigue mats
were associated with lower absolute
MSP intensity in selected body and
associated with lower self-reported
fatigue.

Ergonomic OR chairs showed no
effects in any outcome, including
objectively measured muscle
activity (EMG) and observer-based
posture (RULA). A rotatable
laparoscopic handle showed no
significant effect on objective
muscular stress or fatigue (EMG).
Overall, studies were heterogeneous
and not directly comparable.

Fair (median D&B 18);
heterogeneous designs

D&B = Downs and Black checklist; EMG = electromyography; IMU = inertial measurement unit; MSP = musculoskeletal pain; REBA = Rapid Entire Body Assessment; RULA = Rapid Upper Limb Assessment.

Implications for the subsequent study

This review provided insights into the scope of ergonomic interventions tested in the OR on surgeons' musculoskeletal health. However, the evidence base was methodologically limited, and the reported associations should be interpreted with caution. Despite these limitations, the review identified three pragmatic intervention types associated with modest but relatively consistent favorable findings across intervention types: ergonomic education, microbreaks and OR posture optimization. Accordingly, the three intervention types were included in the development of the Good Ergonomics recommendations (ERGO) and the design of Phase 1 in Study 2.

METHODS STUDY 2

This section describes the two phases that together form Study 2; full details are provided in the protocol (95). Phase 1 involved developing and launching ERGO and administering a questionnaire to assess its uptake. It served as an educational phase intended to establish a basic ergonomic foundation at department level and formed the standard-care condition for Phase 2 (Figure 5, blue arrow), which was the RCT.

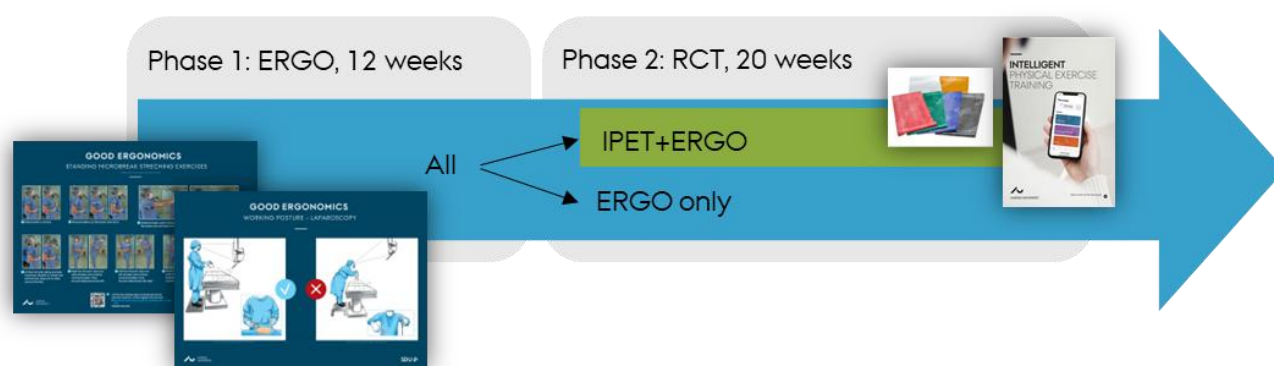


Figure 5 Study 2 two-phase design: 12-week ERGO followed by a 20-week IPET+ERGO randomized controlled trial.

Methods phase 1: ERGO launch and uptake assessment

The ERGO intervention

ERGO comprised two core components drawn from the intervention types identified in Study 1: (1) optimization of working postures in the OR, and (2) regular intraoperative microbreaks. Together, these were intended to reduce the physical work demands and promote muscular activity variation during surgery. Ergonomic education was delivered as a supporting element to facilitate uptake of both components, through oral presentations at surgeons' morning meetings and short informational videos accessible via QR codes on posters (Appendix 1 and Appendix 2).

Where feasible, OR nurses were included to support shared awareness and day-to-day ergonomic practice. Presentation formats varied across departments: most sessions lasted approximately 30 minutes, though some were condensed to as little as 10 minutes due to local time constraints. Across

formats, presentations covered the rationale and evidence underpinning ERGO, practical guidance for application, and time for questions where possible.

The two components were illustrated on posters. OR posture recommendations were illustrated on three modality-specific posters, with the recommendations for LAP illustrated in Figure 6 (OPEN and RAS posters are found in OPEN poster). Standing microbreak recommendations are illustrated in Figure 7 (the seated microbreak poster is found in Appendix 2

Seated microbreak poster).

Microbreak content was adapted and translated into Danish from Mayo Clinic's OR Stretch web app (<https://orstretch.mayoclinic.org/>) and converted into Danish microbreak posters and audio instructions, with permission from the Mayo Clinic. Illustrations are created by our collaborators at Mayo Clinic (47).

Surgeons primarily performing other modalities were encouraged to apply the ergonomic principles when appropriate, and regular microbreaks were emphasized as a relevant strategy applicable across surgical modalities. Surgeons were encouraged to state their microbreak intention at the first check-in of the day, including preferred timing or frequency to support shared expectations within the OR team.

GOOD ERGONOMICS

WORKING POSTURE – LAPAROSCOPY

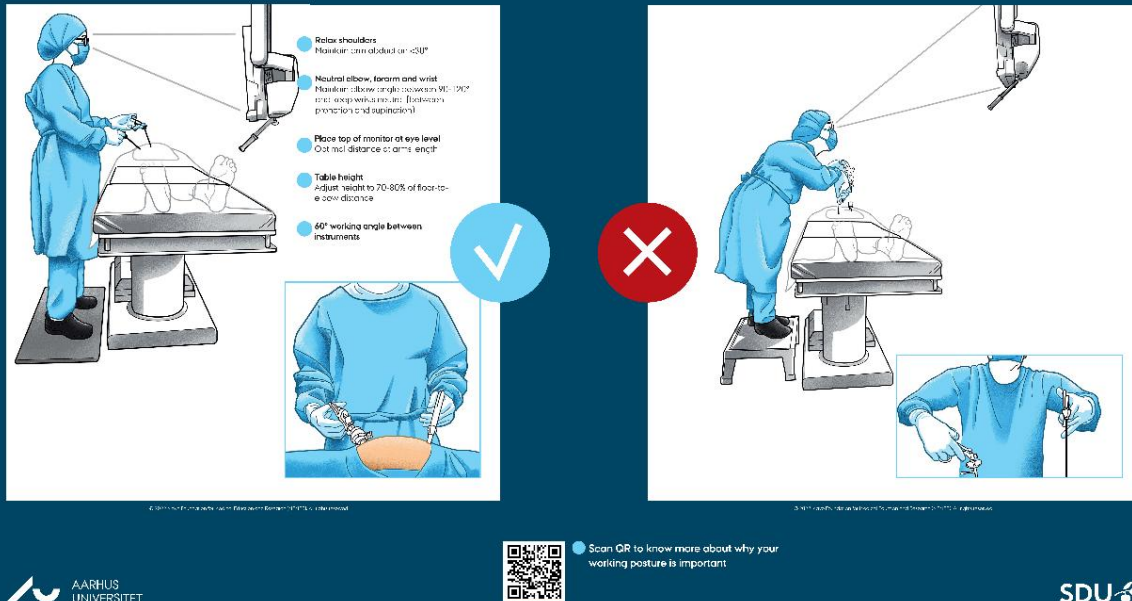


Figure 6 ERGO poster for laparoscopic surgery illustrating recommended (✓) and non-recommended (✗) working postures, including guidance on position and placement of equipment (blue dots).

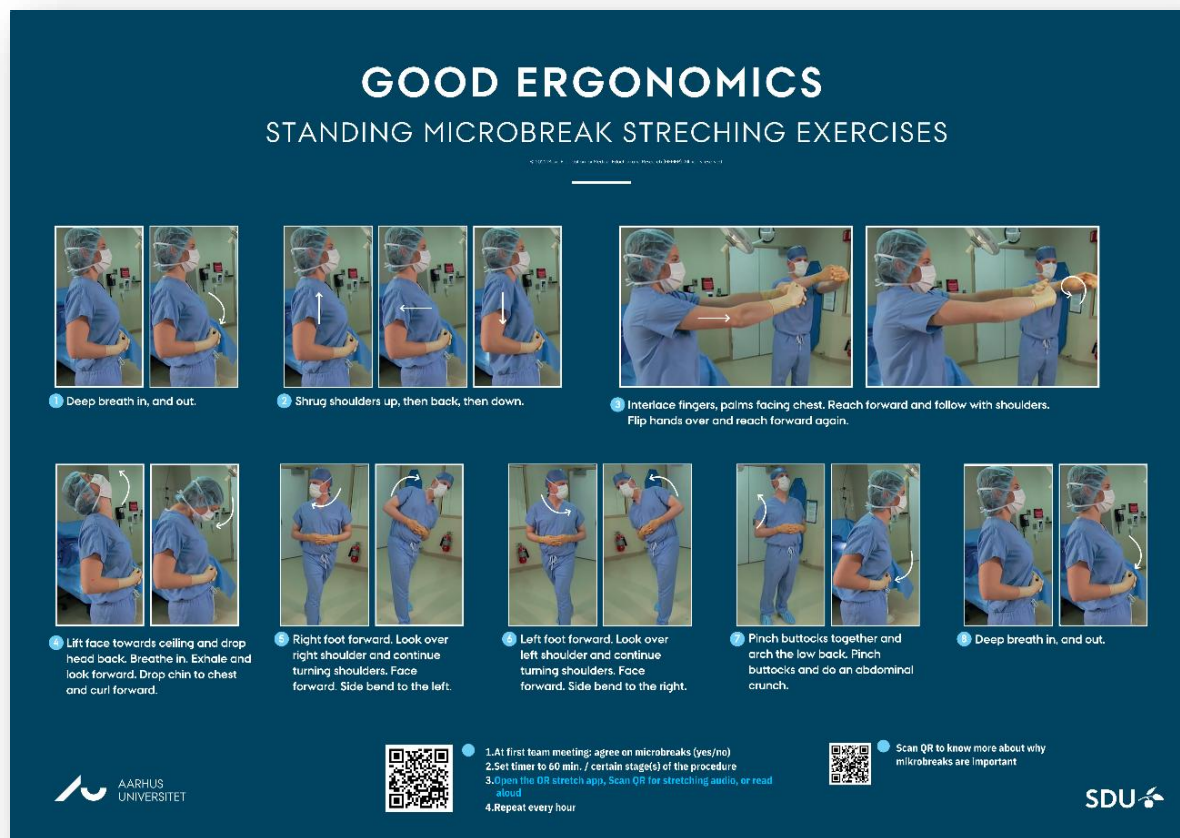


Figure 7 ERGO microbreak poster illustrating standing stretching exercises performed in the sterile field, with guidance on frequency implementation, and a QR code linking to audio instructions.

Theoretical basis and development process

To promote broad use across settings, we restricted ERGO to low-cost ergonomic strategies that were easy to access and could be applied in the OR without relying on additional equipment or local infrastructure. Study 1 findings were refined through dialogue with the national and international team of researchers that were involved in the study, which included surgeons with clinical experience from the target specialties. This ensured that ERGO was aligned with local routines and constraints to maximize feasibility and OR applicability.

To guide the intervention design of ERGO, inspiration was taken from the Behavior Change Wheel (BCW) (96, 97). The BCW builds on the COM-B model, which describes behavior as arising from the interaction between three components: Capability, Opportunity and Motivation. The target behavior

was defined as surgeons' practice of ERGO. In COM-B terms, ERGO aimed to support Capability by providing basic ergonomic knowledge and practical guidance; Opportunity by displaying ERGO posters in the OR environment, and encouraging shared attention to ergonomics within the OR team; and Motivation by explaining how ergonomic practices may contribute to preventing or reducing MSP (Figure 8) (96, 97).

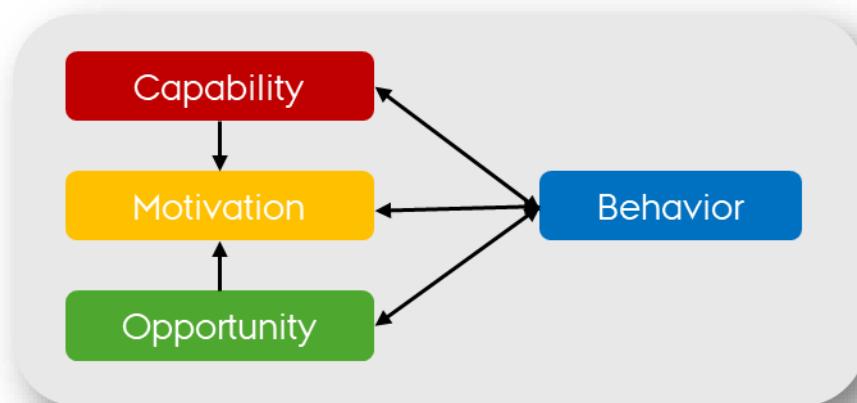


Figure 8 The COM-B framework for understanding behavior

Building on this analysis of the target behavior, selected intervention functions from the surrounding layer of the BCW were incorporated into the ERGO launch (Figure 9, red circle). Education was addressed through oral presentations and short informational videos. Environmental restructuring was addressed by displaying posters in the OR environment. Enablement and training was addressed through practical guidance and, where feasible, support from OR nurses and project staff during the early launch period. Modelling was addressed by encouraging senior surgeons and local representatives to support ERGO practice in the OR. ERGO sweets were offered as incentivization (Appendix 3).

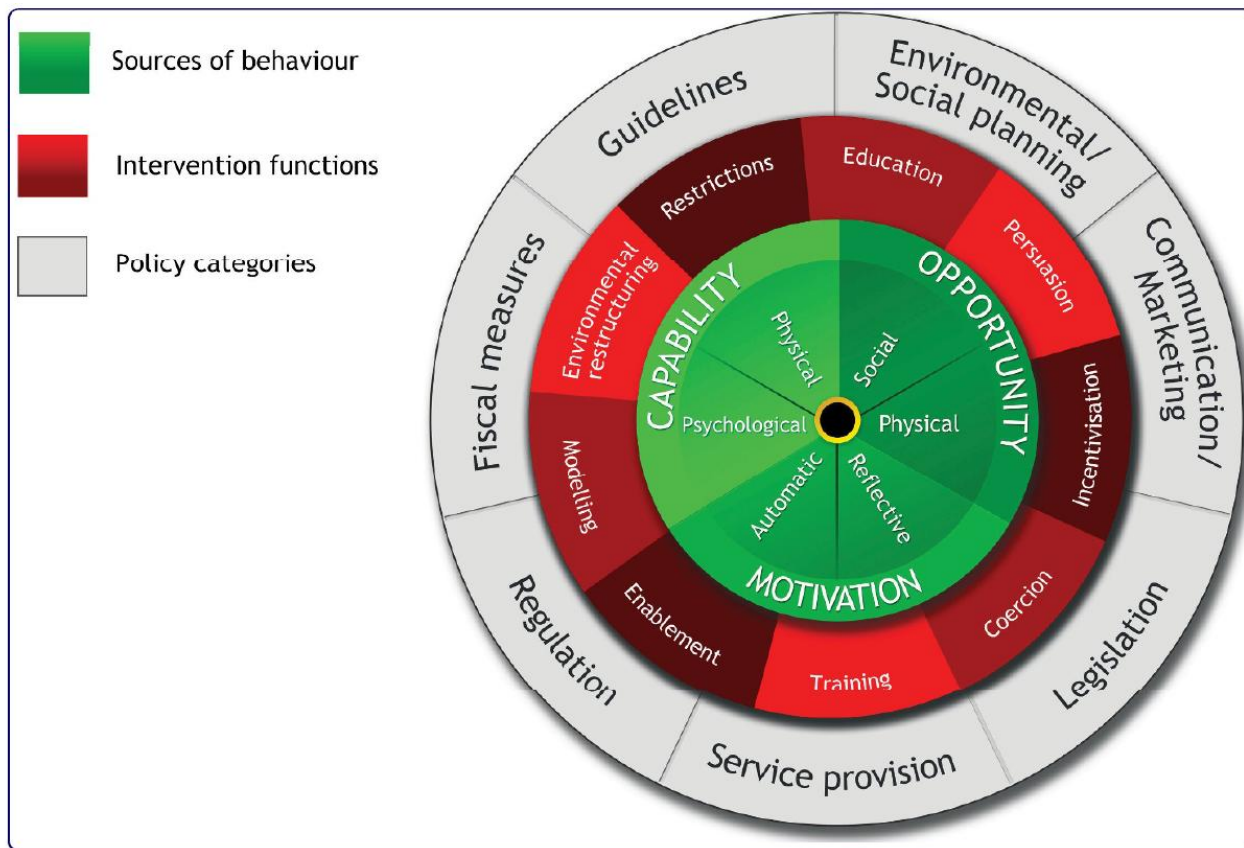


Figure 9 The Behaviour Change Wheel

Launching ERGO at Danish hospitals

Following approval from the department head, we coordinated with each site via e-mail and/or in-person meetings to clarify the scope, agree on local responsibilities, appoint a departmental contact person, and schedule the launch date. This preparatory phase typically required coordination over several weeks/months, depending on local schedules and decision-making processes, as illustrated in Figure 10.

Besides the posters as well as digital materials designed for use in and around the OR environment, the ERGO launch was supported by flyers providing key information and recruitment encouragement and the ERGO sweets to increase visibility and engagement Appendix 3 .

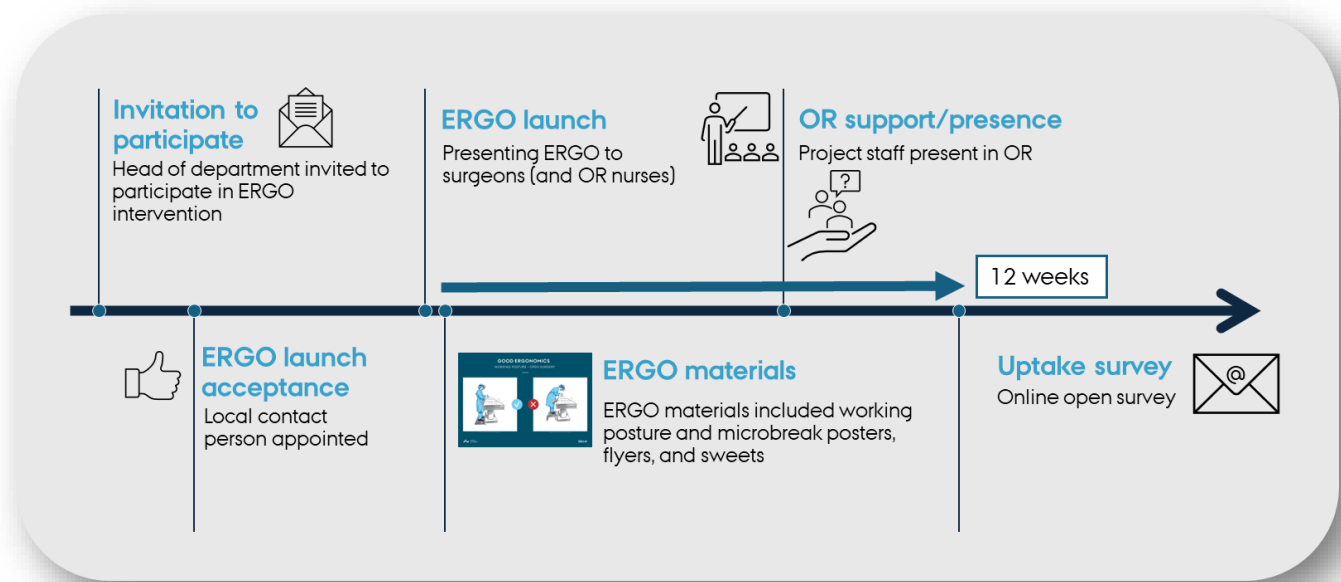


Figure 10 Overview of the ERGO launch activities, from initial department invitation to the 12-week uptake survey

Assessment of ERGO uptake

To evaluate uptake, we developed a project-specific questionnaire to assess surgeons' awareness of the ERGO components and their self-reported uptake of microbreaks and recommended working postures during surgery. Because no validated, surgeon-specific questionnaire existed for these constructs, the questionnaire should be considered explorative rather than psychometrically validated. Most items were developed for this study by the international project team. The BCW and its COM-B framework was used for operationalization of the questionnaire and its uptake constructs.

Awareness was defined as psychological capability (knowing and remembering the recommendations), and practice was defined as ergonomic behavior, which is shaped by social and physical opportunity (e.g., team support, visual cues in the environment) and motivation (e.g., perceived relevance). One item assessing MSP frequency was adapted from the validated Nordic Musculoskeletal Questionnaire (NMQ) (98). MSP was included to describe the symptom context.

The ERGO questionnaire was distributed via an online survey link generated in the REDCap database, approximately 12 weeks post-launch at each site. This time interval was chosen to allow time for ERGO materials to be introduced and used in routine practice before serving as standard-care in

Phase 2. Completion of the ERGO survey served as the trigger for enrolment into Phase 2. An English version of the ERGO questionnaire is found in Appendix 4.

An open survey approach was used to both maximize reach and to minimize the need for direct processing of personal contact information by the research team, as personal e-mail addresses of all potential participants were not available to us. Therefore, a survey link was distributed via local departmental channels, either the contact person or a secretary, who also sent two reminders at one-week intervals.

The REDCap return-code function was enabled to allow participants to resume incomplete questionnaires, which was also applied to reduce the likelihood of multiple records being created if the open link was re-opened. The few duplicate entries ($n=5$) were managed by retaining the most complete record or, when completion was similar, the first entry (by date).

After completing the Phase 1 questionnaire that included a mandatory e-mail field, surgeons received a unique personal link to the Phase 2 questionnaire, after which unique ID's were generated to link within-person responses.

Methods Phase 2: Randomized controlled trial (effectiveness)

While Phase 1 aimed at establishing an ergonomic foundation through the launch of ERGO, Phase 2 aimed at evaluating the effectiveness of adding IPET to ERGO in reducing surgeons' MSP in a randomized controlled trial (RCT). The participants were randomized to either ERGO only (standard care) or IPET+ERGO delivered via the Intelligent Motion app (intervention).

The 20-week RCT in Phase 2 was introduced through oral presentations at department meetings, approximately 2-3 weeks before the end of Phase 1. These sessions presented the rationale for Phase 2, introduced the concept of IPET and the Intelligent Motion app, and outlined eligibility criteria. As part of trial start, elastic bands were distributed to departments to hand out to IPET+ERGO participants only.

Eligibility criteria

Eligible participants were primary and assisting abdominal or pelvic surgeons, specializing in gynecology, urology, or colorectal surgery, performing OPEN, LAP or RAS for a minimum average of four hours per week. Completion of the Phase 1 ERGO survey was a prerequisite for participation in Phase 2. Surgeons were excluded if their general practitioner advised against participation in physical exercise training.

Trial design, setting and timeline

This 20-week RCT had two parallel groups, and was conducted among surgeons in Danish hospital departments that had participated in Phase 1. Participants were randomized individually in a 1:1 ratio, stratified by pain case status (i.e. presence of MSP ≥ 3 rated 0-10 on a numerical rating score (NRS). Outcomes were assessed longitudinally at baseline (pre-intervention), 12 weeks (approx. mid-way), and 20 weeks (post-intervention).

Randomization and allocation concealment

Individual randomization was considered appropriate because the standard-care condition (ERGO) had been offered as a common, department-wide foundation, whereas IPET was prescribed individually and performed independently in or outside of work hours.

Randomization was implemented in REDCap to ensure allocation concealment until assignment, and stratification by MSP pain case status was used to balance baseline MSP levels between groups. Given the nature of the intervention, participants were not blinded to group allocation. However, the statistical analysis and outcome interpretation were conducted blinded to group allocation.

The trial was developed and conducted in close collaboration with the international collaborators who have launched parallel studies at their respective sites. However, the timing of these studies was delayed and places the reporting of them beyond the scope of this thesis.

Intervention groups and delivery

The intervention consisted of standard care (ERGO) for all participants regardless of group assignment, and everyone was encouraged to continue practicing the ERGO components to the same extent as they practiced it in Phase 1. In addition to ERGO, the intervention group received their IPET program via the Intelligent Motion app.

Participants from ERGO who completed the 20-week follow-up were offered access to the app after the intervention period.

IPET delivered via the Intelligent Motion App

The Intelligent Motion app builds upon the concept of IPET (43, 56), that builds on knowledge from health-enhancing sports science principles and incorporates that into a weekly one-hour exercise training program (50 minutes effective training and 10 minutes for warm-up). The IPET program is tailored to job-demands, physical capacity and general health-indicators, including MSP. Early IPET workplace trials from the 2010s typically relied on managerial agreement to exercise during working hours and often required access to exercise facilities and supervisor support, making implementation relatively resource demanding (29). To support a more pragmatic and scalable delivery model, the Intelligent Motion app was designed to make IPET more accessible, less dependent on equipment and facilities, and flexible to perform at a time that suits the participant. The app was developed through collaboration between researchers at SDU and app developers at Trade Expansion/50 Minutes (99). The app generates a weekly 50-minute exercise program based on self-reports and self-assessed measurements which are illustrated as screen shot images in Appendix 5. The underlying IPET algorithm and cut-points used in the app to tailor the IPET program is presented in Table 6.

The weekly 50-min program is divided into two components: job profile and individual profile (Figure 11). The first 20 minutes are allocated according to the participant's job profile and the physical work demands, e.g. a sedentary job profile is prescribed moderate- to high-intensity aerobic training, corresponding to a Borg rating of perceived exertion of 14–15, or around 70-80% of HR_{max} (57, 100). The composition of the remaining 30 minutes depends on individual profile composition, and includes aerobic-, strength- and functional training, or a combination. If muscular strength is rated below average compared to peers and MSP is present, the individual is prescribed 30 minutes of all-round strength training including specific strength training for the painful body region. Each participant was provided with a set of four elastic resistance bands (Theraband) to enable proper intensity in strengthening exercises (details in the protocol (95)).

Participants could update their self-reported prescription variables in the app at any time during the trial, for instance if their MSP shifted to a different body region. An updated entry would generate a revised IPET program reflecting the new pain profile.

Table 6 Self-reported variables and their cut-points in the prescription of IPET programs in the Intelligent Motion app

Domain	Variable	Variable operationalization	
		Question	Cut-Points
Job profile	Occupational exposure category	Response option(s) <i>How would you categorize the physical demands in your main job?</i>	
		1. Mainly sedentary work that does not require physical exertion 2. Work is largely performed while standing or walking 3. Standing or walking work with some lifting and/or carrying activities 4. Heavy or fast-paced work, which is strenuous	1. Sedentary: moderate to high intensity aerobic training 2. Standing/walking: high intensity interval aerobic training + function training 3. + 4. Physically heavy: whole body muscle endurance training
Physical capacity profile	Cardiovascular fitness	<i>How would you score your aerobic capacity compared to others of your own age and sex?</i> Assessed on a 0–10 numerical rating scale (NRS) ranging from as poor to as good as possible	Responses below 5 (corresponding to average) lead to prescription of extra aerobic training
	Muscle strength	<i>How would you score your strength capacity compared to others of your own age and sex?</i> Assessed on a 0–10 NRS ranging from as weak to as strong as possible	Responses below 5 (corresponding to average) lead to prescription of extra all-round strength training

Health profile	Balance and function	Self-assessed standing time on non-dominant leg with the arms crossed over the chest (hands on the shoulders). Three trials are given	If the individual loses balance before reaching 30s, functional training is prescribed
	Body mass index	Assessed as an individual's weight in kilograms divided by the square of height in meters	A body mass index above 25 leads to the prescription of extra aerobic training
	Musculoskeletal pain	<i>For how many days in total have you had (specific body part) pain during the last 3 months/7 days?</i>	
		Yes/no <i>If symptoms have been prevalent for one or more days a follow up question is asked about average pain intensity.</i>	Any symptoms lead to prescription-specific strength training for the body part. If an individual has symptoms in more than two (tree) body parts, the pain intensity guides the prioritization
		Assessed as specific body part pain on a 0-10 NRS ranging from no pain to worst possible	

Intelligent Physical Exercise Training (IPET)

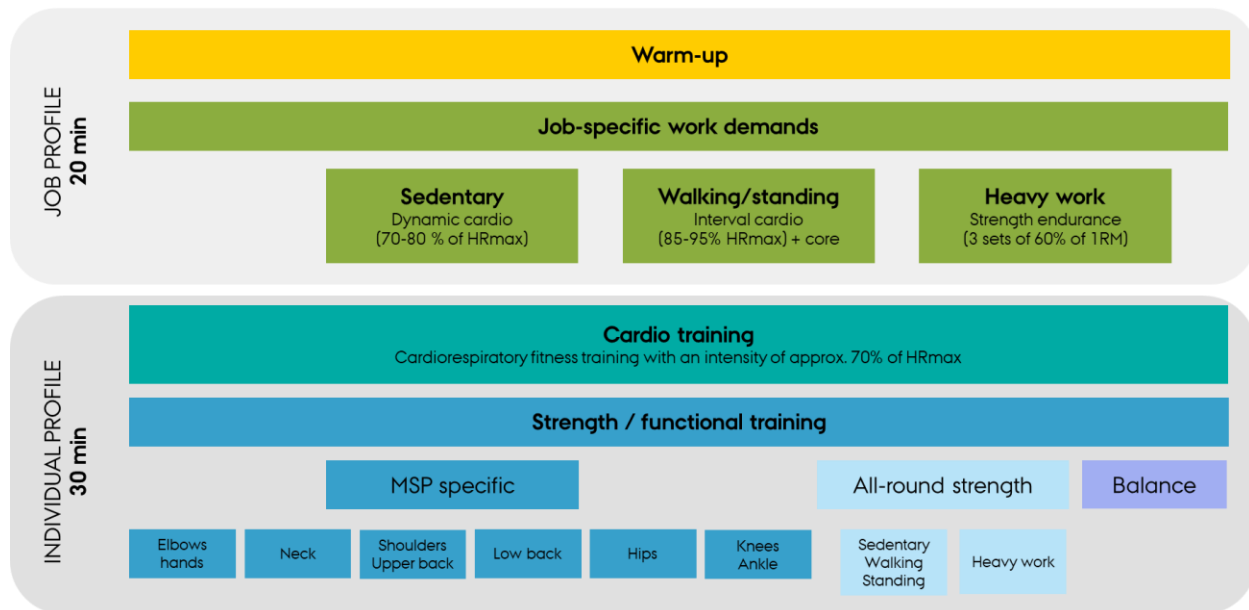


Figure 11 The IPET program structure, comprising a 20-minute job profile component, and a 30-minute individual profile component.

The weekly 50 minutes IPET could be completed in one session or divided into 2-5 shorter sessions with the same effect (101). Completing at least 70% of the prescribed weekly dose (≥ 35 minutes per week) was defined a priori as the threshold for adequate adherence, in line with established IPET adherence criteria (56).

The IPET+ERGO participants could contact project staff for app-related and IPET support. Before being launched in this trial, the Intelligent Motion app was pilot-tested in other populations, including health professionals and university employees (99). After launch, user feedback was continuously forwarded to Tradeexpansion/50 Minutes as part of an iterative quality-improvement process.

Outcomes and measurements

Outcomes were assessed using online questionnaires at baseline, 12 weeks, and 20 weeks. The primary follow-up time point was 20 weeks.

The primary effect of interest was the between-group difference in worst 3-month MSP intensity at 20 weeks. MSP was assessed using a modified version of the Nordic Musculoskeletal Questionnaire (102)

and rated on an 11-point NRS from 0 to 10. For each body region, participants first reported the number of days with MSP during the past three months. If at least one day with MSP was reported, they were asked to rate MSP intensity for that region. Worst MSP was defined as the highest reported MSP intensity score at baseline across the ten assessed body regions: neck, upper back, lower back, shoulders, elbows, wrists/hands, hips, knees, and ankles/feet.

If two or more body regions had the same highest intensity score, the body region with the longest reported duration of MSP was selected. If both intensity and duration were identical, the body region was selected according to the most prevalent painful body region among Danish surgeons (9).

Worst MSP intensity at baseline was selected as primary effect of interest due to the nature of how IPET designs individualized training programs. Of the 50 minutes training program it allocates exercises depending on the severity.

Other MSP outcomes were MSP intensity the past seven days, number of days affected by MSP, number of days MSP interfered with work/private life, and frequency of analgesic use for MSP. Pain-case status was defined as an MSP intensity score of ≥ 3 in at least one body region and was derived from the ten assessed body regions scores. Multisite MSP was defined as having MSP in two or more body regions.

Broader health and work-related secondary outcomes were general health, assessed with a 12-item Short Form Health Survey (SF-12)¹ (103); personal and work-related burnout, assessed with the Copenhagen Burnout Inventory (CBI) (104); and work ability, assessed with the Work Ability Index (WAI)¹ (105). These outcomes were included to describe whether the intervention had broader effects beyond MSP.

Baseline covariates and descriptive variables included demographic and anthropometric characteristics (age, sex, and BMI), work characteristics (surgical specialty and weekly working hours). Physical activity profile was assessed with Saltin-Grimby (106), self-assessed physical capacity with Strøyer (107), and time spent on physical activity weekly with questions from the Danish Health Profile (108).

¹ The SF-12 and WAI were pre-specified as secondary outcomes in the trial protocol and SAP. As the required sample size was not reached until May 2025, data collection continued beyond the originally planned timeline. Therefore, only single-item versions of both instruments are reported here. Complete instrument data are available, but their analysis is outside the scope of this thesis.

Adherence was assessed at 12- and 20-week follow-ups. ERGO practice was assessed by asking participants how often they applied ergonomic working postures and microbreaks during surgery. IPET adherence was assessed in the intervention group as self-reported average weekly minutes of IPET, with ≥ 35 minutes per week corresponding to $\geq 70\%$ adherence to the prescribed 50 minutes per week. Harms were not systematically recorded. However, the proportion of participants with an increase in worst MSP from baseline to follow-up was reported as an indicator of possible worsening. The baseline questionnaire is presented in Appendix 6. The 12- and 20-week questionnaires were identical to the baseline questionnaire, with the addition of follow-up questions on ERGO practice, IPET adherence, and intervention experience.

Questionnaire administration and follow-up procedures

To ensure data completeness, all fields in the baseline questionnaire were marked as mandatory. In the 12- and 20-week follow-up questionnaires, according to participant feedback, some questions about burnout and work ability optional were made optional.

The follow-up protocol specified that participants received two e-mail reminders. However, midway through the trial, this was deviated from because 20-week responses were lower than expected.

Therefore, in the last four departments, a personalized e-mail encouraging completion was sent. As this did not sufficiently improve response, non-responders were also contacted by phone after the second reminder and, if not reached, by text message. In total, seven participants were called or texted. This escalation of follow-up efforts was introduced to help achieve the sample size.

STATISTICS

Study 2, phase 1

Categorical survey responses were summarized using numbers and percentages. The Phase 1 analyses were mainly descriptive and were used to describe ERGO reach, awareness, practice, perceived barriers, and MSP frequency among survey respondents. Associations between MSP frequency and awareness and practice of the two ERGO components were examined using ordinal logistic regression. For these analyses, MSP frequency was collapsed from five to three categories: never/rarely, sometimes, and most of the time/always. The proportional odds assumption was assessed using a Wald test. The correlation between awareness and practice was assessed for each ERGO component using Kendall's rank correlation coefficient (τ_b). A two-sided p-value <0.05 was considered statistically significant.

Study 2, Phase 2

The total target sample size of 58 participants was calculated for the primary outcome of worst MSP intensity at 20 weeks, assuming a minimum important clinical difference of 1.5 NRS points, a common standard deviation of 2.0 NRS points, two-sided $\alpha = 0.05$, and 80% power. Accounting for an anticipated 30% attrition, informed by previous workplace intervention studies (56), the total recruitment target was 83 participants. Detailed sample size assumptions are reported in the protocol (95) and in the statistical analysis plan (SAP) (available at [ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT06112106) (NCT06112106)). All analyses were performed in Stata 17 (StataCorp LLC, College Station, TX, USA) (109).

The primary analysis followed the intention-to-treat principle. The between-group difference in worst MSP intensity at 20 weeks was estimated using a linear mixed model with worst MSP at 12 and 20 weeks as the dependent variable. Fixed effects included time, group allocation, and a time-by-group interaction. Worst baseline MSP intensity was included as a covariate. Random intercepts were specified at the individual level to account for the within-person correlation between repeated observations. The time-by-group interaction was retained to allow group-specific trajectories, with the 20-week between-group contrast as the pre-specified primary estimate. This model was chosen because

it appropriately accounts for the correlation between observations originating from the same participant.

Although randomization blocks were pre-specified as a random intercept, block identifiers were not available in the required format and could not be included. Given the use of small, permuted blocks within a fully randomized design, this is unlikely to have materially affected the estimates. Model assumptions related to linearity, homoscedasticity, and influential observations were assessed by inspection of residual plots.

Missing data were handled under the missing-at-random (MAR) assumption inherent to the linear mixed model. The model uses maximum likelihood estimation across all available observations: every participant with at least one observation contributes to estimation, no values are imputed, and no participant is excluded because of missing follow-up data. Inference under MAR is conditional on the covariates included in the model. Sensitivity to this assumption was examined through a complete-case analysis restricted to participants with primary outcome data at all three points.

Continuous secondary outcomes were analyzed using the same linear mixed-model. Binary outcomes were analyzed using mixed-effects logistic regression. Ordinal outcomes (days with MSP, use of pain medication, and general health score) were analyzed using ordinal logistic regression with cluster-robust standard errors at the individual level, as the corresponding mixed-effects ordinal models did not achieve convergence. The mixed-effects logistic model for multisite MSP likewise did not converge due to quasi-complete separation arising from the high baseline prevalence of multisite MSP, it was therefore replaced by an ordinal logistic regression model with cluster-robust standard errors.

Pre-specified additional analyses included: 1) a per protocol analysis including IPET+ERGO participants with $\geq 70\%$ adherence (≥ 35 minutes of weekly training averaged over the 20-week intervention (56)) and all ERGO participants, to estimate the effect of the intervention under conditions of adequate adherence; 2) an adjusted analysis adjusting for baseline levels of potentially important prognostic factors, including age, sex, BMI, weekly working hours, surgical specialty and physical activity profile; and 3) a complete-case analysis, restricted to participants with primary outcome data available at all time points. According to the SAP, a subgroup analysis by baseline pain case status was pre-specified. However, as randomization was stratified by this variable and 64 of 83 of participants

were pain cases and 19 as no pain-cases at baseline, the subgroups were highly imbalanced, and the analysis was considered uninformative; it is therefore not reported.

Baseline values are presented as observed mean (SD) for continuous variables and as n (%) for categorical variables. 12- and 20- week continuous follow-up values are reported as model-estimated marginal means with standard error (SE) derived from the linear mixed model; these therefore reflect the expected mean under the fitted model rather than a simple average of observed values. For categorical and ordinal outcomes, follow-up values are reported as observed n/N (%), where N denotes the number of participants with available data at that time point. Because participants did not provide complete data at every time point, the denominator N varies by outcome and time point and is reported in each table. Between-group effect estimates with 95% confidence intervals refer to the model-based 20-week contrast and were calculated using all available data under the MAR assumption. The extent and pattern of missing data were described by treatment group and key baseline characteristics. Among IPET+ERGO participants, adherent and non-adherent participants were further compared on baseline characteristics to assess potential differential dropouts. Statistical tests were two-sided, with a statistical significance level of 0.05, and exact p values reported. No adjustment for multiple comparisons was applied. All analyses were performed using Stata version 17 or newer (StataCorp, College Station, TX, USA).

RESULTS STUDY 2

This section presents the findings of the two phases comprising Study 2. Initially, 12 departments were approached and invited to participate in the study. Of these, nine agreed to participate, one was already involved in another research project, one found the study irrelevant, and one did not reply further after indicating interest.

Results phase 1: ERGO launch and uptake

Population, setting and timing

ERGO was launched at five Danish regional ($n=3$) and university hospitals ($n=2$) between October 2023 and October 2025. Across these hospitals, nine surgical departments participated: colorectal ($n=3$), gynecology ($n=3$), and urology ($n=3$). ERGO was intended to reach all surgeons in the participating departments, regardless of seniority and modality. All respondents reported having performed surgery within the past three months. Of these, 75% performed laparoscopy, 36% robot-assisted surgery, and 78% open surgery; responses were not mutually exclusive.

Reach and visibility of ERGO

The ERGO uptake survey was distributed to 313 potentially eligible participants. Of those, 104 surgeons completed it (33%). Overall, 96% of the 104 surgeons reported having seen or heard about ERGO. The oral presentation was the most frequently reported source of ERGO (78%), followed by posters in the OR (72%) and in the respective departments (53%). Consistent with this, awareness of both components was moderate to high, with 93% reporting to have at least some awareness (some, good, very good) of ergonomic working postures and 89% for microbreaks.

Uptake of the ERGO components

ERGO awareness was higher than practice, especially for microbreaks (Table 7): Ergonomic working postures were practiced more frequently, with 85% reporting that they practice ergonomic working postures in the OR most of the time or always, whereas microbreaks were reported less frequently, with 34% reporting that they practiced microbreaks most of the time or always. Across both components,

higher reported awareness was associated with more consistent practice (posture: Kendall's $\tau_b = 0.39$, $p < 0.001$; microbreaks: Kendall's $\tau_b = 0.55$, $p < 0.001$).

Table 7 Self-reported practice of the two ERGO components

Response category	Ergonomic working postures n (%)	Microbreaks n (%)
Always	22 (21%)	4 (4%)
Most of the time	67 (64%)	31 (30%)
Sometimes	8 (8%)	27 (26%)
Rarely	4 (4%)	26 (25%)
Never	1 (1%)	12 (12%)
Don't know	2 (2%)	4 (4%)

Reported barriers to more consistent practice

Table 8 presents reported barriers to more consistent practice for each component. Among the few surgeons who reported practicing ergonomic working postures in the OR sometimes or less ($n = 13$), the most frequently reported barriers were lack of training, and lack of support from leaders. Among the surgeons reporting practicing microbreaks sometimes or less ($n = 65$), the most frequently reported barriers were lack of support from general OR staff, from surgeon colleagues, and training. Twenty-one participants reported “other” barriers, that were elaborated on in the comments field. Seven surgeons indicated a low perceived need for microbreaks during short procedures lasting less than 60 minutes. Several comments also highlighted the importance of senior or attending endorsement in facilitating ergonomic behaviors in the OR.

Table 8 Reported barriers to consistent practice of the ERGO components

Barriers	Posture Among surgeons practicing sometimes or less (n=13)	Microbreaks Among surgeons practicing sometimes or less (n=65)
Lack of training	11 (85%)	24 (37%)
Lack of support from leaders	6 (46%)	18 (28%)
Lack of support from OR staff	-	37 (57%)
Lack of support from surgeons	-	27 (42%)
Lack of information	2 (15%)	7 (11%)
Other	4 (31%)	21 (32%)

n (%) represents the number of respondents. Barriers were not mutually exclusive; respondents could select more than one barrier. Percentages are calculated as the proportion of surgeons practicing sometimes or less for each respective component.

These barrier patterns were also reflected in the surgeons' perceptions of the two ERGO components. Both components were perceived positively at a conceptual level. As seen in Figure 12 and Figure 13, most surgeons agreed/strongly agreed that ergonomic working postures and microbreaks were good ways to prevent MSP (85% and 75%, respectively), and that everyone should follow these recommendations (93% and 85%, respectively). However, perceptions differed when focus shifted from general value to practical use. For ergonomic working postures, 38% agreed or strongly agreed that the posters made operating with good posture easier, and 36% agreed or strongly agreed that they pay attention to their posture when operating. For microbreaks, the corresponding proportions were lower; 13% agreed or strongly agreed that remembering to take them is easy, and 38% agreed or strong agreed that integrating them into workflow is easy. The OR nurse was the most frequently reported microbreak prompt (77%), indicating their important role. Taken together, the barrier and perception findings suggest that posture adjustment was more readily integrated into routine practice, whereas microbreaks appeared more dependent on social support within the OR, reminders, and workflow fit.

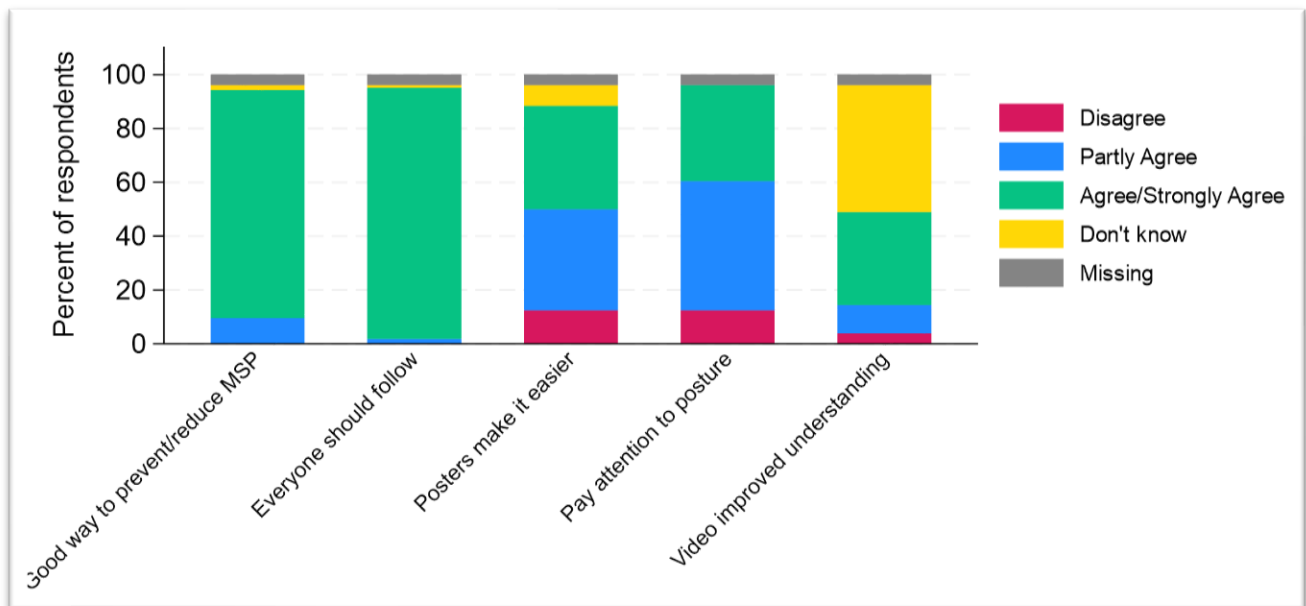


Figure 12 Percentage distribution of responses to statements about the posture component

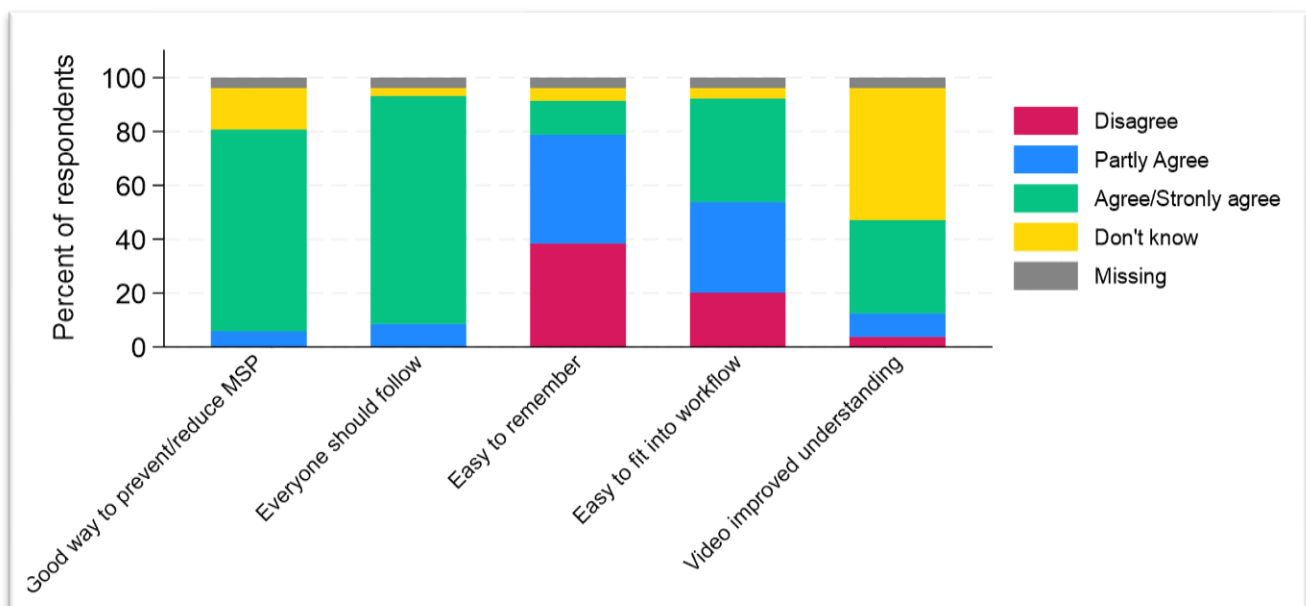


Figure 13 Percentage distribution of responses to statements about the microbreak component.

MSP prevalence in relation to uptake

Overall, 74% reported experiencing MSP at least sometimes with the most affected body regions being the neck, shoulders, and back. Among those with MSP at least sometimes, 79% reported MSP in two or more body regions, indicating frequent multisite MSP. However, MSP frequency (regardless of single and multisite MSP) was not clearly associated with higher awareness or practice of the ERGO components (Table 9). There was no statistically significant association between MSP frequency and posture awareness and practice, whereas frequent MSP (more than sometimes) and microbreak awareness and practice formed a tendency, although not statistically significant.

Table 9 Awareness and practice of ERGO components by MSP frequency

Outcome	Association for surgeons with MSP at least sometimes vs. rarely/never	OR	p-value	Interpretation
Posture awareness	Sometimes vs. never/rarely	0.45	0.08	Lower/no clear trend. No clear evidence.
	Most of the time/always vs never/rarely	0.89	0.82	
Posture practice	Sometimes vs. never/rarely	0.84	0.72	Approximately null. No clear evidence.
	Most of the time/always vs never/rarely	1.13	0.82	
Microbreak awareness	Sometimes vs. never/rarely	1.32	0.54	Higher. Trend, but imprecise.
	Most of the time/always vs never/rarely	1.96	0.17	
Microbreak practice	Sometimes vs. never/rarely	1.66	0.26	
	Most of the time/always vs never/rarely	2.42	0.06	

OR = odds ratio from logistic regression, comparing surgeons reporting MSP at least sometimes with those reporting MSP rarely or never. OR > 1 indicates higher odds in the MSP group. P-values are two-sided.

Summary of Phase 1 findings

Overall, the ERGO launch was associated with high awareness of both ERGO components, but practice was less for microbreaks. Barrier and perception data suggested that microbreak practice was more dependent on social support within the OR, making consistent practice more complex, than posture adjustment which can be considered more individual.

Although awareness was high and uptake varied across components, MSP remained highly prevalent in the sample and showed no clear association with ERGO uptake. Higher awareness was associated with more frequent practice.

Results Phase 2: Effectiveness of adding IPET to ERGO on surgeon MSP

Phase 2 tested whether targeting the surgeon's physical capacity through app-delivered IPET provided additional reductions in MSP beyond ERGO.

Trial flow and analytical sample

Of the 104 surgeons invited to participate in the RCT, 85 (82%) were assessed for eligibility and 83 (80%) were randomized to IPET+ERGO (n=41) or ERGO only (n=42). Two participants were randomized despite not fulfilling the inclusion criterion of at least four hours of surgery per week. As this was identified after randomization, both participants were retained in the intention-to-treat analysis. Primary outcome data were available for 66 participants at 12 weeks (80% of randomized participants) and 60 participants at 20 weeks (72% of randomized participants). Thus, 72% of randomized participants contributed data to the primary endpoint.

The participant flow is shown in Figure 14. The first participant was enrolled in December 2023 and the last participant follow-up was received in May 2026.

The protocol included recruitment from Denmark and the United States; however, the present thesis reports the Danish trial data only as the US intervention roll-out was delayed. Those data will be reported separately.

Baseline symptoms and physical capacity

Baseline demographic, work and health-related characteristics are presented in Table 10. The sample included gynecological (27%), urological (36%), and colorectal (34%) surgeons, and 1 participant categorized as other surgical specialty. Mean weekly working hours were 40.6 (SD 5.0). Participants had a mean age of 48.4 (SD 8.6) years, 64% were female. Fifty-three (64%) were from university hospitals and 30 (36%) were from regional hospitals.

At baseline, 98% of participants reported MSP in the past three months, and 92% reported MSP in two or more body regions (multisite MSP). Pain cases (MSP intensity of ≥ 3 on a 0-10 NRS) constituted 72% of the population.

Mean worst MSP intensity was 3.8 (SD 1.9) assessed on a 0-10 NRS. The body regions most frequently identified contributing to worst MSP were the neck (29%), lower back (23%), knees (13%) and shoulders (11%).

Participants rated their physical capacity to be above their peers, and 43% percent reported at least 150 minutes of moderate-intensity physical activity per week. For vigorous physical activity, 18.5% reported 90 minutes or more per week Table 10.

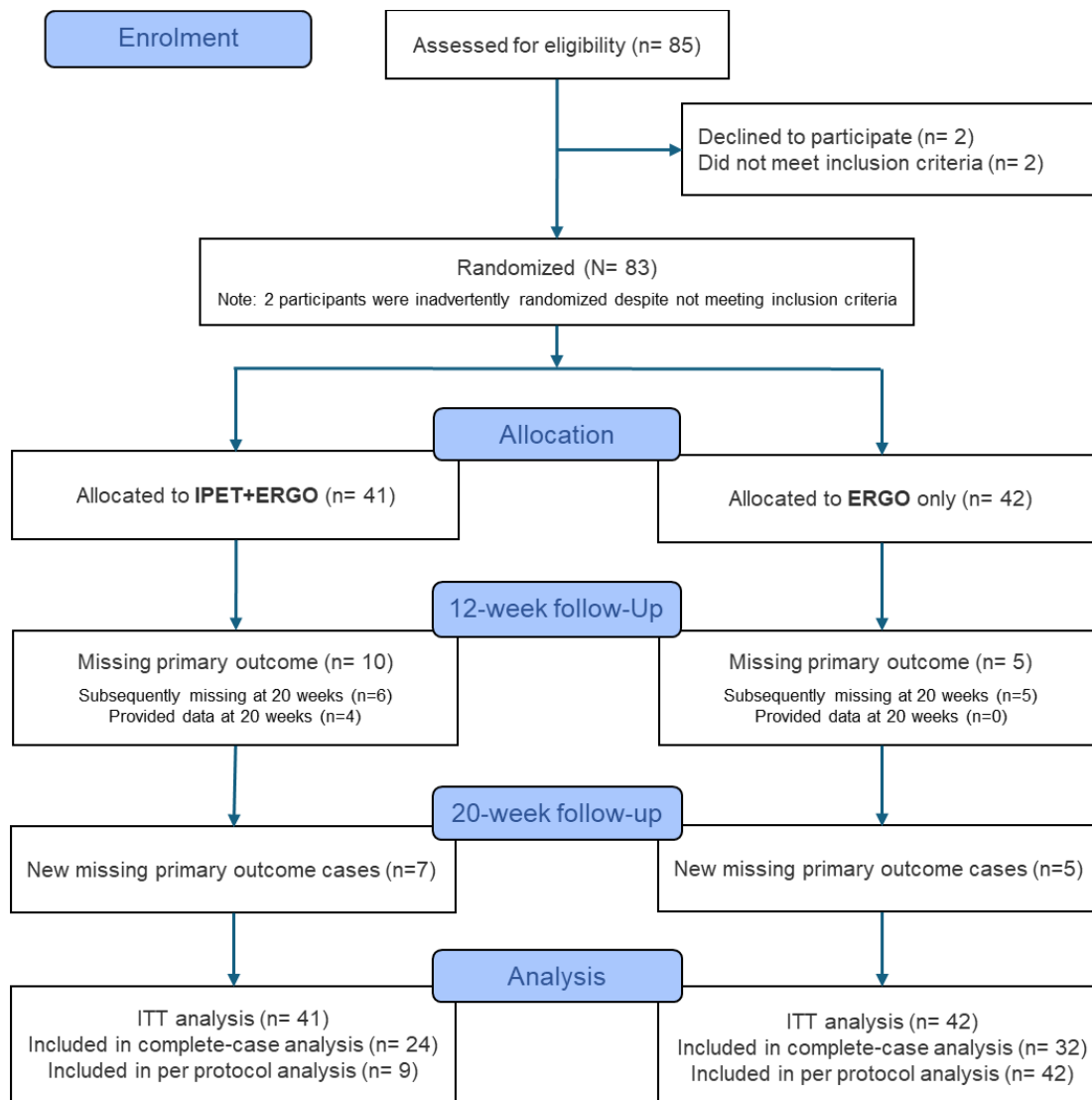


Figure 14 Flow of RCT-participants from enrollment to last follow-up

Table 10 Baseline characteristics of randomized participants

Demographic, work and health-related characteristics	Total (N=83)	IPET+ERGO (n=41)	ERGO (n=42)
Age, years	48.4 (8.6)	48.0 (8.6)	48.8 (8.6)
Female sex	53 (63.9)	26 (63.4)	27 (64.3)
BMI, kg/m²	24.5 (3.3)	25.0 (2.9)	24.0 (3.6)
Surgical specialty			
Gynecology	22 (26.5)	10 (24.4)	12 (28.6)
Urology	30 (36.1)	17 (41.5)	13 (31.0)
Colorectal surgery	28 (33.7)	14 (34.1)	14 (33.3)
Other	1 (1.2)	0 (0.0)	1 (2.4)
Weekly working hours	40.6 (5.0)	40.6 (5.8)	40.7 (3.9)
Work ability score, NRS 0-10	8.9 (1.1)	8.9 (1.0)	8.9 (1.1)
Physical capacity compared with peers, NRS 0-10			
Muscle strength	5.9 (1.9)	5.3 (1.7)	6.5 (1.9)
Cardiovascular fitness	5.9 (2.3)	5.3 (2.2)	6.5 (2.2)
Balance	6.4 (1.7)	6.5 (1.6)	6.2 (1.7)
Leisure-time physical activity level			
Physically inactive	5 (6.2)	3 (7.3)	2 (5.0)
Some light physical activity	39 (48.1)	23 (56.1)	16 (40.0)
Regular physical activity and training	34 (42.0)	14 (34.1)	20 (50.0)
Regular hard physical training for competitive sports	3 (3.7)	1 (2.4)	2 (5.0)
Moderate physical activity per week, minutes			
Less than 150 minutes	46 (56.8)	26 (63.4)	20 (50.0)
150 minutes or more	35 (43.2)	15 (36.6)	20 (50.0)
Vigorous physical activity per week, minutes			
Less than 90 minutes	66 (81.4)	36 (87.9)	30 (75.0)
90 minutes or more	15 (18.5)	5 (12.2)	10 (25.0)
Worst MSP intensity in past 3 months, NRS 0-10	3.8 (1.9)	3.9 (1.9)	3.6 (2.0)
Pain case (overall MSP ≥ 3)	64 (77.1)	32 (78.0)	32 (76.2)
Multisite MSP (≥ 2 sites)	76 (91.6)	40 (97.6)	36 (85.7)

Values are mean (SD) or n (%). Percentages are based on available responses for each variable. Age, sex, BMI, worst MSP intensity, pain case status, and MSP variables were available for all randomized participants (N=83); N= 81 in other variables due to missing responses. Pain case was defined as worst 3-month MSP intensity ≥ 3 on a 0-10 NRS. Multisite MSP was defined as MSP in two or more body regions during the past three months. Physical capacity >5 indicates self-rated physical capacity higher than peers.

Added effect of IPET on worst MSP

Figure 15 illustrates the development in worst MSP intensity from baseline to 20 weeks, while Table 11 presents the primary and main secondary MSP-related outcomes at baseline and 20 weeks. In the primary intention-to-treat analysis, there was no statistically significant between-group difference in worst MSP at 20 weeks (IPET+ERGO vs. ERGO: 0.54, 95% CI -0.41 to 1.50; $p=0.266$). Thus, the trial did not show evidence that IPET+ERGO reduced worst MSP more than ERGO only.

Both groups showed a reduction in worst MSP from baseline to 12 weeks, after which the level remained relatively stable to 20 weeks. The trajectories were similar across groups, and the observed reduction was not greater in IPET+ERGO than in ERGO only. No statistically significant between-group difference was observed at 12 weeks. The pre-specified adjusted analysis and complete-case analysis did not materially change this interpretation.

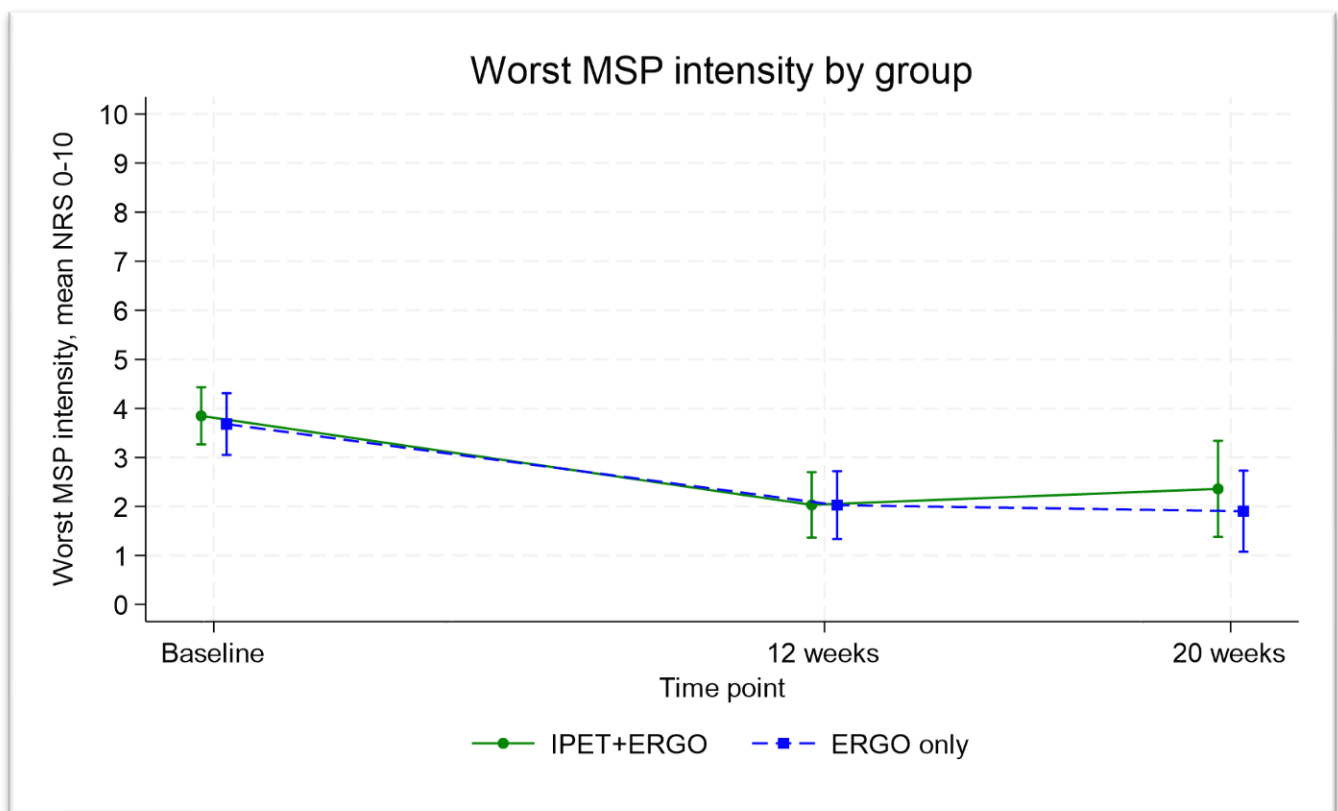


Figure 15 Development in worst MSP intensity from baseline to 20 weeks by group.

Observed mean worst MSP intensity is shown at baseline, and estimated marginal means are shown at 12 and 20 weeks. Error bars indicate 95% confidence intervals. Time points are horizontally offset for visual clarity.

Table 11 Primary and main secondary MSP-related outcomes at baseline and 20 weeks

Outcomes	IPET+ERGO (n=41)		ERGO (n=42)		Between-group effect at 20 weeks (95% CI)	P value
	Baseline	20 weeks	Baseline	20 weeks		
Worst MSP intensity over last 3 months, NRS 0-10	3.9 (1.9)	2.50 (0.35)	3.6 (2.0)	1.95 (0.34)	0.54 (-0.41 to 1.50)	0.266
Worst MSP intensity in past 7 days, NRS 0-10	3.2 (2.2)	2.27 (0.36)	3.4 (2.3)	1.30 (0.34)	0.97 (0.00 to 1.95)	0.049
Pain case (overall MSP ≥ 3), n (%)	32 (78.0)	12/28 (42.9)	32 (76.2)	9/32 (28.1)	8.46 (0.39 to 181.53)	0.172
Multisite MSP (≥ 2 regions)	40 (97.6)	20/28 (71.4)	36 (85.7)	24/32 (75.0)	0.58 (0.16 to 2.04)	0.392
Days with MSP past 3 months, ≥ 1 day	41 (100.0)	20/28 (71.4)	40 (95.2)	20/32 (62.5)	1.66 (0.59 to 4.70)	0.337
Days prevented from work due to MSP in past 3 months, ≥ 1 day	8 (19.5)	2/28 (7.1)	10 (23.8)	3/32 (9.4)	0.77 (0.10 to 5.71)	0.796
Use of pain medication for MSP, one or more times per month	19 (46.3)	11/28 (39.3)	16 (38.1)	5/32 (15.6)	2.70 (0.75 to 9.68)	0.127

Baseline values are observed mean (SD) or n (%). For continuous outcomes, 20-week values are model-estimated marginal means (SE). For categorical outcomes, 20-week values are observed n/N (%) because denominators varied across outcomes. Effect estimates are from intention-to-treat analyses at 20 weeks. For continuous outcomes, effect estimates are mean differences, with positive values indicating higher values in the IPET+ERGO group than in the ERGO only group. For categorical outcomes, effect estimates are odds ratios. For ordinal outcomes, the displayed category is a simplified summary for readability, whereas effect estimates and p values are based on the full ordinal response distribution as presented in Paper IV. Follow-up proportions are descriptive and should not be interpreted as paired within-person changes from baseline, as denominators differed between time points.

Secondary MSP outcomes

As shown in Table 11, secondary MSP-related outcomes did not show a consistent pattern in favor of either group. At 20 weeks, the direction of the between-group effects varied. Estimates favoring ERGO only was pain case status, days with MSP in the past three months, and pain medication, whereas other favored IPET+ERGO, including multisite MSP and days prevented from work. Worst MSP intensity in the past seven days was the only secondary MSP-related outcome with a statistically significant

between-group difference, favoring ERGO only (0.97, 95% CI 0.00 to 1.95; $p=0.049$). Overall, the secondary MSP-related outcomes did not support an additional benefit of IPET beyond ERGO.

Descriptively, the proportions for most MSP-related outcomes decreased from baseline to 20 weeks in both groups, including pain case status, multisite MSP, MSP in the past three months, days prevented from work due to MSP, and use of pain medication. These within-group changes should be interpreted cautiously because follow-up data were incomplete and denominators differed between baseline and follow-up.

Harms were not systematically recorded. As an indicator of possible worsening, an increase in worst MSP from baseline to 20 weeks was observed in 6/41 participants in IPET+ERGO and 3/42 participants in ERGO. Full details are reported in Paper IV.

Broader health and work ability

General health, work ability, and burnout outcomes did not differ statistically between groups at 20 weeks. Descriptively, personal burnout decreased in both groups, and work-related burnout also decreased in the IPET+ERGO group. However, these within-group changes should be interpreted cautiously, as they were not accompanied by statistically significant between-group differences. Overall, these outcomes did not indicate that adding IPET to ERGO improved broader health or work-related outcomes more than ERGO only. For work ability and general health (not shown here), however, high baseline scores may have limited the potential for measurable improvement. Full results are reported in Paper IV.

Further, both groups showed statistically significant within-group increases in self-assessed physical capacity. Muscle strength increased by 0.67 points in IPET+ERGO and 0.66 points in ERGO from baseline to 20 weeks, and cardiorespiratory fitness by 0.74 in IPET+ERGO and 0.53 in (0-10 NRS; all $p < 0.05$).

Table 12 General health, work ability, and burnout outcomes by treatment group

Outcomes	IPET+ERGO (n=41)		ERGO (n=42)		Between-group effect at 20 weeks	P value
	Baseline	20 weeks	Baseline	20 weeks		
General health, good or better, n/N (%)	41 (100)	27/27 (100)	40 (95)	32/32 (100)	1.36 (0.44 to 4.17)	0.594
Work ability, 0-10	8.9 (1.0)	9.2 (0.2)	8.9 (1.1)	8.9 (0.2)	0.24 (-0.25 to 0.73)	0.337
Personal burnout, 0-24	8.3 (3.3)	6.3 (0.5)	7.2 (3.3)	6.2 (0.4)	0.14 (-1.07 to 1.35)	0.816
Work-related burnout, 0-28	7.8 (4.7)	5.9 (0.5)	6.5 (3.6)	6.3 (0.5)	-0.39 (-1.86 to 1.08)	0.602

Values are presented as mean (SD) at baseline and model-estimated marginal mean (SE) at 20 weeks for continuous outcomes. Categorical outcomes are presented as n/N (%), where N denotes the number of participants with available data at the given time point. Effect estimates represent the model-based between-group difference at 20 weeks. For general health, the effect estimate is an odds ratio. Higher work ability scores indicate better work ability. Higher burnout scores indicate higher burnout.

Intervention exposure and adherence

At 20 weeks, self-reported ERGO practice remained uneven across the two components. Among participants with available data, most reported practicing ergonomic working postures always or most of the time, whereas microbreaks were practiced less consistently. Specifically, 94% reported practicing ergonomic postures always or most of the time, compared with 22% microbreaks. This pattern was consistent with the Phase 1 findings, where posture adjustments were practiced more frequently than microbreaks.

Self-reported IPET adherence was limited. Of the 41 participants randomized to IPET+ERGO, 24 provided IPET adherence data at 20 weeks. Among these, the mean training dose was 32 minutes per week. Nine participants, corresponding to 22% of the IPET+ERGO group, met the predefined adherence threshold of at least 35 minutes per week. Among adherent participants, the mean weekly training dose was 58 minutes, indicating that some participants completed more than the prescribed dose.

Supplementary and robustness analyses

The pre-specified supplementary analyses did not materially change the interpretation of the primary analysis. The adjusted analysis controlling for age, sex, BMI, surgical specialty, weekly working hours, and physical activity profile produced estimates similar to the intention-to-treat analysis. So did the

complete-case analysis, restricted to participants with primary outcome data at baseline, 12 weeks, and 20 weeks.

The per-protocol analysis, including the nine IPET+ERGO participants who met the predefined adherence threshold, showed a more pronounced estimate, also favoring ERGO, but the confidence interval was wide (1.35; 95% CI -0.07 to 2.77; $p=0.062$). Because the adherent subgroup was small, this analysis should be interpreted cautiously and does not provide clear evidence of an added effect of IPET under conditions of adequate adherence.

Follow-up data were available for 66 participants at 12 weeks and 60 participants at 20 weeks.

Participants with missing primary outcome data at 20 weeks were older than those with available data, while no clear differences were observed for sex, BMI, weekly working hours, leisure-time physical activity level, or surgical specialty. Complete cases did not differ clearly from non-complete cases on baseline MSP, pain case status, multisite MSP, or other key baseline characteristics. Among IPET+ERGO participants, no clear baseline differences were observed between adherent and non-adherent participants. Thus, missing data reduced precision and may have introduced some bias, but the adjusted and complete-case analysis did not materially change the overall finding of no clear added effect of IPET. Table 13 presents the primary, adjusted and sensitivity comparisons.

Table 13 Comparison of primary, adjusted, complete-case, and per-protocol analyses

Analysis	Population	Effect estimates for worst MSP at 20 weeks (95% CI)	P value	Interpretation
ITT primary analysis	All randomized with available outcome data	0.54 (-0.41 to 1.50)	0.266	No clear between-group difference
Adjusted analysis	Adjusted for baseline covariates	0.63 (-0.38 to 1.63)	0.223	Similar to primary analysis
Complete-case analysis	Complete primary outcome data at all time points	0.59 (-0.47 to 1.64)	0.274	Similar to primary analysis
Per-protocol analysis	9 adherent IPET+ERGO + ERGO only	1.35 (-0.07 to 2.77)	0.062	No clear between-group difference, wide CI, trend favoring ERGO

DISCUSSION

Summary of main findings

The overall aim of this thesis was threefold. First, to identify ergonomic interventions positively associated with surgeon musculoskeletal health and workload. Second, to translate this into evidence-informed ergonomic recommendations targeted at abdominal and pelvic surgeons and to launch these across multiple departments in Denmark, and third, to test the added effectiveness of IPET in addition to ERGO.

In the systematic review, Study 1, ergonomic education was most consistently associated with reductions in the proportion of surgeons reporting MSP, and microbreaks were most consistently associated with reductions in absolute MSP intensity and fatigue. OR posture optimization was most consistently linked to improvements in biomechanical or observer-based measurements. Body support devices and miscellaneous ergonomic devices showed less consistent patterns.

Building on Study 1, low-cost pragmatic ergonomic interventions were selected for Study 2, phase 1. The pragmatic ERGO launch was associated with high awareness of both ERGO components, whereas practice was uneven, with lower consistent practice of microbreaks. There was no clear evidence that MSP frequency was associated with higher awareness or practice, although a tendency towards higher microbreak practice was observed among surgeons reporting more frequent MSP, and in general, higher awareness was associated with more frequent practice.

In Study 2, phase 2, the RCT tested whether adding app-delivered IPET to ERGO provided additional reductions in MSP. There was no statistically significant between-group difference in worst MSP intensity. Both groups reduced worst MSP from baseline to 20 weeks by approximately 1.4-1.7 points, which is within the range considered clinically relevant (64).

Fitting the OR to the surgeon: reducing work demands in the OR

Ergonomic interventions are recommended by national health and safety regulatory authorities (110), and the European Agency for Safety and Health at Work for the prevention of MSP among workers in the health care sector (3). Systematic reviews similarly call for greater attention to ergonomic training across surgical specialties to prevent and manage MSP among surgeons (4, 27, 111, 112). More

recently, studies and expert recommendations have also called for greater physical fitness among surgeons (52, 59-61). However, the proposed training protocols have generally not been grounded in established exercise science guidelines such as IPET. Thus, surgical ergonomics should be considered a necessary foundation for reducing physical work demands in the OR, yet, the broad endorsement of surgical ergonomics does not necessarily mean that the evidence for specific ergonomic interventions is conclusive in MSP management. In Study 1, ergonomic education, microbreaks, and posture optimization showed the most consistent positive findings, but the overall evidence was limited by substantial heterogeneity and modest quality that lowered the overall confidence in the findings. Nonetheless, despite these methodological limitations, the physiological rationale for these intervention types is well-established. Surgical work often requires prolonged static postures and sustained low-level muscle activity. Surgeons' focus is so directed at the operative task and the patient that their awareness of accumulating physical strain may be limited (113, 114). Over time, this may increase intramuscular pressure, compromise local blood flow, and promote metabolite accumulation, contributing to muscular fatigue and MSP (28). This may help explain the duration-dependent pattern observed in Study 1, where microbreaks were most consistently effective in reducing MSP in procedures exceeding two hours, and in addition, associated with improved mental focus and performance (16, 78, 79). A similar lag between biomechanical improvement and subjective pain relief may account for why posture optimization more consistently improved observer- and sensor-based biomechanical parameters than self-reported MSP intensity. The relatively short observation periods in most of these studies (the duration of a surgical procedure (80-85)) may have limited the ability to detect meaningful reductions in MSP. Evidence from mixed working populations suggests that ergonomic interventions can produce clinically relevant MSP reductions, but that sustained effects may require longer intervention periods (115, 116). Consistent with this, the ergonomic education studies, which had the longest follow-up periods among the included studies (two months to one academic year (18, 51, 73-76)), were also those most consistently associated with reductions in the proportion of surgeons reporting MSP, suggesting that a longer practice period may be needed before postural improvements translate into subjective pain relief.

Ergonomic awareness and practice in surgical settings

Despite increased attention to surgical ergonomics over the last decades, several reviews suggest that ergonomic principles are still not systematically integrated into surgical education or routine OR practice (8, 27, 112). This gap appears to begin early in the surgical training pathway, as medical schools and hospitals provide little formal ergonomic education during training (48, 49). This is important because greater ergonomic awareness may support ergonomic practice, as suggested by previous survey findings (53). Relatively simple educational sessions may improve ergonomic awareness and encourage practice of ergonomic principles in the OR (50, 51, 76). This was confirmed in Study 2, phase 1, where a brief, low-intensity introduction to the ERGO components was associated with high awareness of ERGO and frequent self-reported practice of ergonomic postures. However, practice differed between components, as microbreaks were practiced less consistently than ergonomic postures. This may reflect that ergonomic posture adjustments can often be initiated by the individual surgeon, whereas microbreaks depend on coordination with the OR team. More consistent microbreak practice may therefore require greater attention to the organizational dimension of ergonomics thorough structured introduction, leadership support, and integration into surgical workflow (117-119). Although the ergonomic interventions primarily target external work demands, one important dimension not addressed in the present thesis is the gender perspective. The ergonomic challenges facing female surgeons warrant particular attention, as the proportion of women in surgical specialties has increased steadily over the last decade (120-122). However, OR environments and surgical instruments have historically been designed around male anthropometry, placing female and small-handed surgeons at a disproportionate ergonomic disadvantage (38). Female surgeons working under these conditions may therefore be exposed to comparatively greater physical demands, given generally lower absolute muscle strength and differences in body proportions.

Taken together, the ERGO findings support the relevance of improving the fit between the OR and the surgeon from a work demand perspective. Consistent practice of ERGO may reduce awkward postures, static loading, and provide rest breaks to support muscular and mental recovery (16, 78, 79).

According to the work demand-capacity model (Figure 2), the hypothesis was that fitting the OR to the surgeon would not be enough to alleviate the high prevalence of MSP and high intensities. This

provided the rationale for adding IPET, which targeted the surgeon's physical capacity and was expected to produce greater reductions in MSP than ERGO only.

Fitting the surgeon to the OR: Increasing physical capacity as a complementary strategy

Adding app-delivered IPET to ERGO did not result in a statistically significant between-group difference in worst MSP at 20 weeks. This lack of between-group effects contrasts with much of the previous IPET evidence. Across various working populations, IPET has demonstrated beneficial effects across several outcomes, including reductions in MSP, improvements in physical capacity and selected health risk indicators, and positive effects on productivity and company-level economic outcomes (29). In mixed working populations there was an overall reduction in MSP from approximately 3 to 2 (0-9 NRS), with larger reductions in pain cases where MSP decreased almost by half from around 5 to under 3. A dose-response pattern was suggested, with the largest MSP reductions among participants with high training adherence (55, 116, 123). A trial among military helicopter pilots similarly found no significant between-group effect, but reported significant within-group reductions in neck pain intensity following 20 weeks of self-administered IPET and similarly low adherence (124). A similar pattern was also observed among office workers, where the IPET and control groups reduced MSP within groups without a significant between-group contrast (125), consistent with the present findings. The lack of a clear added effect of IPET should be interpreted in the light of several interrelated factors.

Low training adherence and exercise compliance

Low training adherence and unknown exercise compliance are the most likely explanations for the lack of a clear added effect of IPET. Within the demand-capacity model, IPET was included to increase the surgeon's physical capacity and reduce relative workload and MSP. However, this requires that the training is actually performed with sufficient dose and intensity. While training adherence describes whether participants completed the prescribed 50 min. of training weekly, exercise compliance concerns whether the exercises were performed with sufficient intensity and progression, both essential for muscular adaptations and reductions in MSP (29).

In the present trial, overall adherence to IPET was low, and exercise compliance was not measured in

detail. The IPET strength component was prescribed through elastic bands and app guidance, but the extent to which participants progressed the load or trained at sufficient intensity was unknown. However, both groups increased self-reported muscular strength and cardiorespiratory fitness statistically from baseline to 20 weeks, but whether this reflects a true training effect cannot be confirmed. Notably, the increase in self-reported muscular strength was similar in both groups, which may indicate that some ERGO participants increased their physical exercise independently during the trial period. This is a form of contamination that could have contributed to the within-group MSP reductions observed in the ERGO group. Obtaining clinically relevant MSP reductions appears to depend on a strength training adherence of minimum 70% and on exercise compliance defined by sufficient training volume and load progression. Total training volume (accumulated load) must be high, this is especially true for women, and progression from baseline of one to two times the initial load has been identified as particularly important (123). None of these parameters could be verified in the present trial.

ERGO as an active comparator

A second and related explanation is that ERGO functioned as an active comparator rather than a non-treatment control. In contrast to most previous IPET trials, which compared IPET to a passive or no-treatment control, the present trial compared IPET+ERGO to ERGO alone. All participants were encouraged to apply the ERGO components throughout the trial, and both groups reduced worst MSP from baseline to 20 weeks by approximately 1.4 points in IPET+ERGO and 1.7 points in ERGO - reductions that fall within the range commonly considered clinically meaningful (64). The magnitude of these within-group reductions is broadly consistent with MSP reductions reported following ergonomic education and microbreak interventions among surgeons (51, 78, 79). This raises the possibility that ergonomic awareness, better working postures, and supported muscular recovery through microbreaks may in themselves contribute to MSP reduction, as indicated in Study 1. Consistent with this, surgeons generally rated their health as good or better, and work ability was high throughout the trial period. This finding contrasts with broader healthcare populations where multisite MSP has been associated with poorer work ability (14). Nevertheless, the independent effect of ERGO cannot be confirmed from the present trial design, and the evidence on ergonomic interventions among workers with physically demanding work remains mixed (126). Regardless, the active nature of the

comparator condition means that any additional effect of IPET had to exceed an already active intervention. This threshold may have been difficult to meet given the low training adherence, exercise compliance and sample size.

IPET delivery mode

A third explanation and another important difference from several previous IPET interventions is the mode of delivery. In many earlier studies, exercise was delivered at or near the workplace, often during paid working hours and with some degree of supervision or organizational support (43). In contrast, IPET was delivered via an app in the present trial, and surgeons were encouraged to incorporate IPET into their own routines, either during leisure time or during work when possible, emphasizing that the 50 min. could be divided into shorter sessions for flexibility with the same effect (101).

This seems to have been insufficient to support participation in this setting and population, where clinical demands are high and work schedules are unpredictable. Unlike many previously studied occupational groups (28), surgeons' attention during working hours is directed toward the patient and the operative task, leaving little room for health behaviors such as exercise (127-129). Further, interview data from Danish surgeons suggest that some surgeons may be reluctant to perform physical exercise during working hours, as they view this time as dedicated to patient care rather than their own health (130). The app-delivery mode may therefore have shifted much of the initiative and responsibility to the individual surgeon.

The absence of supervision support likely intensified these challenges. This may have affected both motivation to continue training and the quality of the training performed. In qualitative research on workplace exercise, feeling left alone in the intervention and lacking regular contact with the research team have been identified as barriers to sustained motivation (131). Regular motivational outreach, for example weekly messages acknowledging progress may have supported adherence in the present trial. In addition, although the app had been pilot-tested (99), it underwent several updates during the trial period as part of the adaptation for use at the partner sites in the US. These may have affected participant experience and engagement.

Thus, it can be argued that the trial tested the effectiveness of app-delivered IPET, and whether a low-support, app-based format could be integrated into surgeons' everyday routines. The findings do not

exclude that IPET may be beneficial under other delivery conditions, but suggest that it must be better integrated into the surgical work setting.

Implementation in a surgical setting

Beyond individual adherence challenges, implementation at the team and organizational level represented a central barrier that has affected both ERGO and IPET throughout the trial.

In Study 2, phase 1, OR nurses were the most frequently reported prompt for microbreaks, yet OR nurse briefing was not consistent across all departments which may have contributed to variation in microbreak practice across departments. This suggests that the team level may be a critical but under addressed implementation target.

At the team level, the OR team as a whole was not directly targeted in either ERGO or IPET. ERGO was directed at surgeons, and microbreak practice depended on individual initiative within a team that had received no specific preparation, except for the encouragement of the lead surgeon to state their microbreak intention for the day. This mismatch between an individually directed intervention and a team-dependent behavior may partly explain the lower and less consistent microbreak practice observed in Study 2, phase 1. Colleague and peer support have been identified as important facilitators of behavior change in the OR (132), and in Study 2, phase 1, lack of support from OR staff and from surgeon colleagues were the two most frequently reported barriers to microbreak practice.

At the organizational level, leadership engagement was minimal. This was a deliberate choice, intended to minimize the burden of participation and make the intervention as easy as possible for department heads to accept, without requiring formal commitment or structural change. In retrospect, however, this may have been a major limiting factor. Without visible organizational endorsement, protected time, or local facilitation, both ERGO and IPET competed with the existing demands of surgical work rather than being embedded within them.

In some departments, initial support from project staff and OR nurse involvement was present, but this was not consistent across sites and may have introduced variation in local ERGO uptake, although not further investigated.

Previous implementation research suggests that workplace health interventions are more likely to succeed when they are supported verbally and practically by management, integrated into existing

routines, and facilitated by local champions (117, 128, 129, 131). None of these conditions were systematically present in the current trial.

This partly reflects the position of the research team as external initiators of change in a setting where departmental engagement was difficult to secure (117). Recruitment proved difficult despite the involvement of a senior and well-known figure in Danish surgical circles to facilitate access.

Recruitment ran from autumn 2023 to autumn 2025, and despite this extended period, gaining access to busy OR settings proved consistently challenging. This points to a broader tension in the field: the gap between the well-documented personal and professional consequences of surgeon MSP on the one hand, and the limited willingness or capacity to prioritize participation at both the departmental and individual level on the other (117, 128). This tension may reflect a surgical culture in which enduring physical discomfort is normalized and prioritizing one's own physical health remains secondary to patient care (133, 134).

Methodological considerations

Each study and phase of this thesis had methodological limitations that should be considered when interpreting the findings. These are discussed below, organized by study and phase, and summarized in Table 14.

Study 1: Systematic review

The review had several methodological strengths. Screening, quality assessment, and data extraction were conducted independently by two reviewers throughout, with a third available to resolve disagreements, and critical appraisal was done in pairs. The search strategy was developed with input from a research librarian, the review was pre-registered in PROSPERO, and the search was updated in 2024. Decisions were discussed with the international collaborators, which strengthened both the analytical process and interpretation of findings. The review also had several methodological limitations. Endoscopy and vaginal-access (natural orifice) were excluded despite posing comparable ergonomic demands, which may have narrowed the scope of included evidence. An inclusive approach to study design was motivated by an expectation of a limited number of eligible RCTs. This resulted in a majority of observational studies, which reduced the strength and certainty of the synthesized evidence. To enable consistent quality appraisal across this mixed evidence base, the D& checklist was applied to all study designs for critical appraisal, deviating from the registered protocol which specified design-specific tools (RoB 2, ROBINS-I, and AXIS). This approach improved comparability but may have introduced some imprecision in quality ratings. The GRADE approach was not applied, mainly due to heterogeneity of the evidence at the outcome level. Accordingly, the findings should be interpreted as a broad mapping of available intervention evidence rather than as strong evidence of effectiveness.

Restricting inclusion to interventions delivered in real OR settings improved ecological validity, but real-world conditions also limit experimental control, which may partly explain the modest and heterogeneous effects observed.

The broad outcome criteria introduced substantial variation in both outcome domains and assessment methods, which limited comparability across studies and synthesis of findings. Studies were grouped by primary intervention type to organize the heterogeneous literature in a clinically meaningful way. However, the ergonomic education interventions were multi-component and combined several

ergonomic strategies within a single intervention. Accordingly, the observed effects may reflect the combined influence of several interacting components rather than a single, clearly isolated intervention. The registered synthesis plan specified structuring results by surgical modality, but given the heterogeneity of included studies, the synthesis was instead structured by intervention type to improve clinical utility.

Study 2, phase 1: ERGO components, launch and assessment

Phase 1 had several methodological strengths. The ERGO launch reached nine surgical departments across Denmark from both regional and academic hospital settings. The questionnaire was purpose-built with input from representatives of the target group and pilot tested prior to use. Reporting followed the STROBE and CHERRIES guidelines for observational and internet-based surveys, respectively. The COM-B framework provided a structured theoretical basis for questionnaire design and interpretation of the uptake findings. However, there were also several limitations.

ERGO represents a selection of the findings from Study 1, as low-cost, scalable ergonomic interventions were pragmatic and feasible, thereby excluding equipment- or resource-dependent interventions. The uptake findings therefore apply to pragmatic, behavior-based ergonomic strategies, not to the full range of possible ergonomic interventions.

The ERGO launch strategy was deliberately low-intensity, comprising an oral presentation, access to short videos, posters displayed in and around the ORs, and in some departments, presence in the OR and briefing of OR nurses. This approach was chosen to make ERGO feasible across multiple departments within the time, staffing, and financial constraints of this PhD project. The uptake findings should therefore be understood as reflecting this pragmatic approach, not the potential of a full implementation strategy.

Variation in launch activities across departments may have contributed to inconsistent uptake across sites. The low survey response rate (33%) means that findings are limited to those who responded. It is unknown whether respondents were representative of the wider study population, and it is possible that surgeons with greater interest in surgical ergonomics were more likely to participate (135).

Target group fit may have varied in some departments. ERGO was developed mainly for surgeons performing OPEN, LAP and RAS. However, in some participating departments, endoscopy and vaginal-access procedures represented a substantial part of clinical practice, which may have reduced

the relevance of the ERGO materials and contributed to the low response rate. In practice, all surgeons were encouraged to apply ERGO to the extent that was relevant to them, with particular emphasis on the microbreak component as broadly applicable across all modalities.

An open survey approach was used to maximize reach and minimize bureaucratic requirements. This approach did not prevent multiple submissions from the same individual, though duplicate e-mail addresses were checked and removed. However, this risk was considered low given the clinical workload of the target group.

No validated questionnaire existed for assessing awareness and practice of the ERGO components, and a purpose-built questionnaire was therefore developed; uncertainty remains regarding its construct validity and reliability. Self-reported awareness and practice may not reflect actual behavior.

Consequently, the ERGO findings should be interpreted as descriptive of this specific population and launch context.

The cross-sectional study design means that without baseline measurements, it cannot be concluded that the reported awareness and practice were direct results of ERGO. Instead, the survey data provides a picture of ergonomic awareness and practice at the point of transition into the RCT.

Study 2, phase 2: Trial design, adherence and missing data

Phase 2 had several methodological strengths. The trial was pragmatic and conducted across several Danish surgical departments, increasing the relevance of findings to routine clinical settings. It was preregistered and conducted according to a prespecified SAP, and the main results were interpreted with groups blinded to allocation. Stratified randomization by pain case status ensured balance on a key prognostic variable. The primary outcome was a validated pain scale with a predefined threshold for what counts as a clinically meaningful change. The outcome was based on the body region with the highest MSP intensity at baseline, meaning the analyzed region differed between participants. This approach was chosen because IPET tailors the exercise program to each individual's worst MSP, capturing each participant's most clinically relevant body region. If a participant's worst MSP shifted during the trial and the app was updated to reflect a new worst region, this would only occur if the initial body region had improved. This would be captured as a reduction in the primary outcome. The extent to which such shifts occurred is unknown, but they are unlikely to have introduced systematic bias.

Phase 2 also had several limitations. The absence of a third no-intervention group prevents comparison of ERGO and IPET+ERGO in isolation, or the effect of IPET compared to no intervention. Individual randomization was deemed acceptable because ERGO was delivered at the department level to all staff, and IPET was individually prescribed. However, given the variation in ERGO delivery across departments, cluster randomization by department may have been more appropriate. Additionally, randomization blocks were not included in the statistical model, which may have resulted in marginally underestimated standard errors and slightly too narrow confidence intervals, although the extent of this is unknown. Furthermore, only surgeons who completed the Phase 1 follow-up questionnaire were eligible for RCT enrolment, which may have introduced selection bias prior to randomization, as the most engaged surgeons were likely overrepresented in the trial sample (136). The trial was preregistered to include data from both Danish and collaborating US sites, however, the US data will be reported separately due to delayed roll-out. This deviation increases the homogeneity of the sample and strengthens transferability to other Danish abdominal and pelvic surgical departments, but limits generalizability to international settings.

Attrition at follow-up was within the anticipated range (30%), but it remains unknown whether loss to follow-up was random or systematically related to the intervention, which could introduce attrition bias. App updates implemented during the trial may have introduced variations in the interface and functionality, potentially affecting the user experience and engagement for some participants.

Adherence outcomes were self-reported, which may have introduced measurement error, and exercise compliance was not recorded in the trial follow-up, although the app recorded some exercise compliance metrics, the reporting of them is outside the scope of this thesis. As participants were not blinded to group allocation, self-reported outcomes may be subject to response bias, though this is an inherent challenge in open-label trials of this type and is offset by the subjective nature of MSP as an outcome.

Table 14 Overview of methodological limitations and potential biases across studies and phases

Study / phase	Bias type	Source	Direction	How addressed
Study 1	Selection bias	Endoscopy and vaginal-access modalities excluded despite comparable ergonomic demands; predominantly observational studies due to limited eligible RCTs	Unclear	Inclusive study design criterion stated a priori; scope of exclusion acknowledged and rationale provided
	Misclassification bias	Multi-component interventions grouped by primary type; observed effects may reflect combined components rather than a single isolated intervention	Unclear	Categorization described transparently; limitation acknowledged in synthesis
Study 2, Phase 1	Non-response bias	33% survey response rate; surgeons with greater interest in ergonomics or higher MSP burden more likely to respond.	Overestimation	Open survey approach to maximize reach; non-response rate and direction of potential bias reported transparently
	Recall bias	ERGO developed for OPEN/LAP/RAS surgeons; endoscopy and vaginal-access prevalent in some departments, potentially reducing perceived relevance and response likelihood	Unclear	All surgeons encouraged to apply relevant components; microbreak component emphasized as broadly applicable across modalities
		Self-reported ERGO awareness and practice assessed retrospectively; may not reflect actual behavior	Overestimation	Findings interpreted as descriptive only; no causal claims made about behavior change
		Chronological bias	Unclear	Data framed as a snapshot at the point of transition into the RCT, not as evidence of change attributable to Phase 1
Study 2, Phase 2	Confounding	ERGO was delivered department-wide but with variation in launch intensity across departments - e.g. differences in research staff presence and OR nurse involvement. As randomization was at the individual level, this variation was not balanced between groups and may have independently influenced MSP outcomes.	Unclear	Variation in ERGO delivery described and acknowledged; individual randomization stratified by MSP case status, but not by department-level ERGO exposure.
	Selection bias	Only Phase 1 questionnaire respondents eligible for RCT enrolment; most engaged surgeons likely overrepresented prior to randomization	Overestimation	Acknowledged as an inherent design constraint; eligibility criteria pre-specified in the trial protocol

	Performance bias	Open-label design; participants aware of group allocation may have modified their behavior during the trial	Underestimation	IPET was offered to control group participants after the intervention period
	Attrition bias	Open-label design; MSP and adherence outcomes reported more favorably 30% loss to follow-up at 20 weeks; unknown whether loss was random or systematically related to group allocation or symptom burden	Overestimation	Inherent limitation of open-label trials; not addressed
			Unclear	Attrition within the pre-specified anticipated range; missing-at-random assumption applied in mixed model; complete case analysis reported
	Adherence bias	Participants who adhered to IPET may differ systematically from those who did not, could distort the ITT estimate beyond simple dilution of effect	Underestimation	Adherent and non-adherent participants were compared at baseline and showed no systematic differences, suggesting adherence was not strongly related to participant characteristics
	Recall bias	MSP intensity assessed over the preceding 3 months; ERGO and IPET adherence self-reported retrospectively over 12- and 20-week periods.	Unclear	No specific measures were taken to address recall bias

Bias types and definitions are based on the Catalogue of Bias (catalogofbias.org)

Implications

Implications for clinical practice

Surgeon MSP is common, has personal and professional consequences. This calls for change at multiple levels. The findings of this thesis suggest that both ergonomic practice and physical exercise training are relevant approaches to MSP management among surgeons. However, the evidence also suggests that they are unlikely to be effective as an add-ons to existing clinical demands, or without structural support. The following implications are therefore directed not only at the individual surgeon, but equally at the surgical team, the department, and hospital leadership.

Ergonomic posture education is a feasible and low-threshold entry point for MSP prevention in surgical departments, as posture adjustment can largely be initiated by the individual surgeon without requiring changes to team behavior or workflow. For ERGO, incorporating a brief ergonomic check into the existing surgical time-out procedure, covering table height and monitor position, and microbreak intention. This may offer a practical strategy for embedding ergonomic practice into routine workflow (118).

Microbreak practice, however, requires shared understanding of its purpose, a workflow that accommodates timing, and a team culture in which brief pauses are accepted rather than perceived as disruptions. Future interventions targeting microbreak practice may therefore need to actively involve the OR team as a whole, involving scrub nurses, anesthesia staff, and other OR personnel, rather than relying on one profession and individual intention alone. Because of the high personnel turnover (including surgical trainees and rotating students), this should be done as part of onboarding or at regular intervals (137).

For IPET, offering an initial period of on-site or supervised exercise instruction to the app and the exercises may support both training adherence and exercise compliance. Alternatively, surgeons may benefit from as little as two minutes of progressive resistance training per day for 10 weeks, which has produced clinically relevant MSP reductions in healthy workers with frequent neck and shoulder symptoms (138).

At the organizational level, MSP prevention initiatives is unlikely to be sustained at the departmental level without visible institutional and management endorsement, protected time for exercise, and integration of ergonomic and physical health priorities into existing personnel policies and occupational

health strategies (117, 128, 129, 131, 132). Without this, both ERGO and IPET risk being experienced as additional demands imposed on already pressured clinicians, rather than as supported and valued parts of working life.

Finally, integrating ergonomic education and attention to physical capacity into surgical residency curricula may be a more effective long-term strategy than targeting surgeons already in established practice. This way, surgeons start their surgical careers with norms that prioritize ergonomics and physical capacity and may be better protected against MSP in the future. This should be paired with ergonomic onboarding in the clinical training modules as a formal requirement just like other safety procedures such as sterile technique and surgical time-out.

Among surgeons already in established practice, MSP carries consequences that extend beyond the individual, including sick leave, practice modification, and early retirement (4, 9, 17). These outcomes represent a loss of surgical capacity that is costly both for the employer and for patients. Evidence further suggests that surgeon MSP is associated with impaired surgical performance, with direct implications for patient safety (20-22). Both microbreaks and IPET have also been shown to support rather than undermine productivity: microbreaks do not prolong operative time but help to maintain mental focus and performance (16, 78, 79), and IPET-adherent participants increased productivity by 6% and sickness absenteeism by 29% in a workplace setting (139). MSP management therefore carries an organizational and economic rationale that goes beyond individual wellbeing.

Implications for research

Future trials building on the present design should consider a three-arm design comparing ERGO only, IPET only and IPET+ERGO, or even a four-arm design with a clean control group. This would allow the contribution of each component to be estimated separately and provide a more informative basis for clinical recommendations than the present two-arm design permitted. A cluster randomized design could ensure a more strict separation of intervention components across sites. For IPET specifically, future trials should consider on-site or supervision, at least initially, alongside protected training time, and local facilitation to ensure sufficient training dose and quality. The entire OR team should also be included as an active target of the intervention. To better understand the implementation challenges observed in the present trial, including low adherence and attrition, a qualitative interview study of

surgeons' experiences with participation, or non-participation, could provide valuable insights for future work and inform future intervention design and implementation strategies.

More broadly, surgical ergonomic intervention studies would benefit from larger sample sizes and longer intervention and follow-up periods, as short interventions of a preventive nature may not capture the true effect of the intervention within a short time frame (140). Outcome standardization is also needed as no single validated outcome measurement tool has been established in this field, and terms such as pain and discomfort are frequently used interchangeably. Developing a core outcome set (COS) for surgical ergonomics research would further strengthen the evidence base by enabling more direct comparisons across studies. This could include a standardized measure of MSP intensity (0-10 NRS), subjective workload (NASA-TLX), an observer-based postural assessment such as REBA or objective measure of physical workload such as EMG or posture motion technology. The ERGO survey instrument developed for Study 2, phase 1 to assess awareness and practice of ergonomic recommendations could serve as a starting point for a standardized uptake instrument in surgical ergonomics research. Psychometric validation across surgical settings could establish it as a reusable tool for future intervention studies.

CONCLUSION

This thesis aimed to develop, launch, and evaluate strategies to manage MSP among abdominal and pelvic surgeons, applying a stepped approach from evidence synthesis to intervention development, launch, and testing effectiveness.

The systematic review identified ergonomic education, microbreaks, and posture optimization as the intervention types most consistently associated with improvements in surgeon musculoskeletal health, though the evidence base was limited by heterogeneous study designs, small samples, and variable methodological quality. By restricting inclusion to interventions delivered in live OR settings, the review provides a novel and more clinically grounded evidence base than previously available.

Following the ERGO launch across nine Danish surgical departments, awareness of both components was high, but practice was uneven. Posture adjustment was reported consistently by most surgeons, whereas microbreak practice was less consistent. This pattern may reflect its dependence on team support. The findings show that a low-intensity launch can achieve high awareness, but that posture adjustment and microbreaks face fundamentally different implementation challenges; the former can be initiated individually, the latter depends on the team.

In the RCT, adding app-delivered IPET to ERGO did not produce a statistically significant between-group difference in worst MSP at 20 weeks. Both groups reduced MSP within the range commonly considered clinically meaningful. Low training adherence and the active nature of the ERGO comparator were the most plausible explanations. The trial ultimately tested whether low-support, app-delivered IPET could reduce MSP when delivered with minimal instruction and institutional support. Under these conditions, the intervention was not delivered in sufficient dose to produce a measurable added effect. These findings suggest that establishing that app-delivered IPET without instruction or institutional support is not sufficient in this population, while leaving open whether adequately supported IPET could produce meaningful reductions in surgeon MSP.

The findings point to a broader pattern: both ergonomic practice and exercise training are sound strategies for addressing surgeon MSP, but neither is likely to work when delivered as an add-on to existing clinical demands without structural support.

Taken together, this thesis maps the available ergonomic intervention evidence, describes what a pragmatic ergonomic launch can and cannot achieve, and provides the first RCT evidence on a

combined ergonomic and exercise training intervention for surgeon MSP. The central lesson is that the effectiveness of these strategies depends highly on the conditions under which they are delivered. Ultimately, sustaining surgeon musculoskeletal health may require a broader shift in the surgical culture where ergonomic practice and physical capacity are recognized as professional priorities rather than individual responsibilities.

REFERENCES

1. World Health Organization. Musculoskeletal health 2022 [Available from: <https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions>.
2. de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Luxembourg: European Agency for Safety and Health at Work; 2019.
3. Clarke M, Vroonhof P, Snijders J, de Winter T, van Scheijndel P, van Dorst P, et al. Musculoskeletal health and risk factors in the health and social care sector – a review of existing information. Luxembourg: European Agency for Safety and Health at Work; 2025.
4. Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of Work-Related Musculoskeletal Disorders Among Surgeons and Interventionalists: A Systematic Review and Meta-analysis. *JAMA Surg.* 2018;153(2):e174947.
5. Treede R-D, Rief W, Barke A, Aziz Q, Bennett MI, Benoliel R, et al. Chronic pain as a symptom or a disease: the IASP Classification of Chronic Pain for the International Classification of Diseases (ICD-11). *Pain.* 2019;160(1):19-27.
6. Organization WH. International Statistical Classification of Diseases and related health problems: Alphabetical index: World Health Organization,; 2004.
7. GlobalData Plc. The Complexities of Physician Supply and Demand: Projections From 2021 to 2036. Washington, DC: Association of American Medical Colleges,; 2024.
8. Stucky CH, Cromwell KD, Voss RK, Chiang YJ, Woodman K, Lee JE, et al. Surgeon symptoms, strain, and selections: Systematic review and meta-analysis of surgical ergonomics. *Ann Med Surg (Lond).* 2018;27:1-8.
9. Dalager T, Sogaard K, Boyle E, Jensen PT, Mogensen O. Surgery Is Physically Demanding and Associated With Multisite Musculoskeletal Pain: A Cross-Sectional Study. *J Surg Res.* 2019;240:30-9.
10. Bishop AG, Uhl TL, Zwischenberger JB, Meyerson SL. Prevalence and Impact of Musculoskeletal Pain Due to Operating Among Surgical Trainees. *J Surg Educ.* 2023;80(5):676-81.
11. Yang L, Money SR, Morrow MM, Lowndes BR, Weidner TK, Fortune E, et al. Impact of Procedure Type, Case Duration, and Adjunctive Equipment on Surgeon Intraoperative Musculoskeletal Discomfort. *J Am Coll Surg.* 2020;230(4):554-60.
12. Steadman S, Seibel C, Hallbeck MS, Norasi H, Zhang A, Chrouser K. The impact of work-related pain on surgical team members' burnout and personal and professional performance. *Am J Surg.* 2025;250:116508.
13. Møller CM, Clausen T, Aust B, Eiberg JP. A National Study on Burnout and Pain in Vascular Surgery. *European Journal of Vascular and Endovascular Surgery.* 2026;14(5):377-81.
14. Phongamwong C, Deema H. The impact of multi-site musculoskeletal pain on work ability among health care providers. *J Occup Med Toxicol.* 2015;10(1):21.
15. Gutierrez-Diez MC, Benito-Gonzalez MA, Sancibrian R, Gandarillas-Gonzalez MA, Redondo-Figuero C, Manuel-Palazuelos JC. A study of the prevalence of musculoskeletal

- disorders in surgeons performing minimally invasive surgery. *Int J Occup Saf Ergon*. 2018;24(1):111-7.
16. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Appl Ergon*. 2017;60:334-41.
 17. Dixon F, Vitish-Sharma P, Khanna A, Keeler BD. Work-related musculoskeletal pain and discomfort in laparoscopic surgeons: an international multispecialty survey. *Ann R Coll Surg Engl*. 2023;105(8):734-8.
 18. Allespach H, Sussman M, Bolanos J, Atri E, Schulman CI. Practice Longer and Stronger: Maximizing the Physical Well-Being of Surgical Residents with Targeted Ergonomics Training. *J Surg Educ*. 2020;77(5):1024-7.
 19. Alleblas CCJ, de Man AM, van den Haak L, Vierhout ME, Jansen FW, Nieboer TE. Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive Surgery: A Systematic Review. *Ann Surg*. 2017;266(6):905-20.
 20. Adams SR, Hacker MR, McKinney JL, Elkadry EA, Rosenblatt PL. Musculoskeletal Pain in Gynecologic Surgeons. *J Minim Invasive Gynecol*. 2013;20(5):656-60.
 21. AlSabah S, Al Haddad E, Khwaja H. The prevalence of musculoskeletal injuries in bariatric surgeons. *Surg Endosc*. 2019;33(6):1818-27.
 22. Davis WT, Fletcher SA, Guillaumondegui OD. Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. *J Surg Res*. 2014;189(2):207-12 e6.
 23. Alleblas CC, Formanoy MA, Konemann R, Radder CM, Huirne JA, Nieboer TE. Ergonomics in gynecologists' daily practice: A nationwide survey in The Netherlands. *Work (Reading, Mass)*. 2016;55(4):841-8.
 24. International Association for the Study of Pain. The impact of psychosocial factors on MSK pain 2023 [Available from: https://www.iasp-pain.org/wp-content/uploads/2023/11/psychosocial-factors-msk-fact-sheet_R1.pdf].
 25. Engel GL. The Need for a New Medical Model: A Challenge for Biomedicine. *Science*. 1977;196(4286):129-36.
 26. Dalager T, Jensen PT, Eriksen JR, Jakobsen HL, Mogensen O, Sogaard K. Surgeons' posture and muscle strain during laparoscopic and robotic surgery. *Br J Surg*. 2020;107(6):756-66.
 27. Barrios EL, Polcz VE, Hensley SE, Sarosi GA, Mohr AM, Loftus TJ, et al. A narrative review of ergonomic problems, principles, and potential solutions in surgical operations. *Surgery (United States)*. 2023;174(2):214-21.
 28. Sogaard K, Sjogaard G. Physical Activity as Cause and Cure of Muscular Pain: Evidence of Underlying Mechanisms. *Exerc Sport Sci Rev*. 2017;45(3):136-45.
 29. Sjogaard G, Mann S, Jensen JSD, Oestergaard AS, Dalager T. The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders. *J Electromyogr Kinesiol*. 2021;61:102600.
 30. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol*. 2004;14(1):13-23.
 31. Sutton E, Irvin M, Zeigler C, Lee G, Park A. The ergonomics of women in surgery. *Surg Endosc*. 2014;28(4):1051-5.

32. Cooper H, Lau HM, Mohan H. A systematic review of ergonomic and muscular strain in surgeons comparing robotic to laparoscopic approaches. *J Robot Surg.* 2025;19(1):252.
33. Dalager T, Sogaard K, Bech KT, Mogensen O, Jensen PT. Musculoskeletal pain among surgeons performing minimally invasive surgery: a systematic review. *Surg Endosc.* 2017;31(2):516-26.
34. Plerhoples TA, Hernandez-Boussard T, Wren SM. The aching surgeon: a survey of physical discomfort and symptoms following open, laparoscopic, and robotic surgery. *J Robot Surg.* 2012;6(1):65-72.
35. Sers R, Forrester S, Zecca M, Ward S, Moss E. The ergonomic impact of patient body mass index on surgeon posture during simulated laparoscopy. *Appl Ergon.* 2021;97:103501.
36. Yang L, Wang T, Weidner TK, Madura JA, 2nd, Morrow MM, Hallbeck MS. Intraoperative musculoskeletal discomfort and risk for surgeons during open and laparoscopic surgery. *Surg Endosc.* 2021;35(11):6335-43.
37. Aaron KA, Vaughan J, Gupta R, Ali NE, Beth AH, Moore JM, et al. The risk of ergonomic injury across surgical specialties. *PLoS One.* 2021;16(2):e0244868.
38. Hislop J, Orth D, Tirosh O, Isaksson M, Hensman C, McCormick J. Does surgeon sex and anthropometry matter for tool usability in traditional laparoscopic surgery? A systematic review and meta-analysis. *Surg Endosc.* 2023;37(9):6640-59.
39. Bellini MI, Amabile MI, Saullo P, Zorzetti N, Testini M, Caronna R, et al. A Woman's Place Is in Theatre, but Are Theatres Designed with Women in Mind? A Systematic Review of Ergonomics for Women in Surgery. *J Clin Med.* 2022;11(12).
40. Basager A, Williams Q, Hanneke R, Sanaka A, Weinreich HM. Musculoskeletal disorders and discomfort for female surgeons or surgeons with small hand size when using hand-held surgical instruments: a systematic review. *Syst Rev.* 2024;13(1):57.
41. Lloyd GL, Chung ASJ, Steinberg S, Sawyer M, Williams DH, Overbey D. Is Your Career Hurting You? The Ergonomic Consequences of Surgery in 701 Urologists Worldwide. *J Endourol.* 2019;33(12):1037-42.
42. Johnson G, Roy H, Webber S, Shariff F, Helewa R, Hochman D, et al. Colorectal surgeon physical pain and conditioning: a national survey. *Can J Surg.* 2025;68(1):E64-e70.
43. Sjøgaard G, Sogaard K, Hansen AF, Østergaard AS, Teljigovic S, Dalager T. Exercise Prescription for the Work-Life Population and Beyond. *J Funct Morphol Kinesiol.* 2023;8(2).
44. International Ergonomics Association (IEA). What Is Ergonomics (HFE)? [Internet]. 2025 [Cited 2025 Oct 30]. Available from: <https://iea.cc/about/what-is-ergonomics/>.
45. National Institute for Occupational Safety and Health (NIOSH). Step 1: Identify Risk Factors [Internet]. 2024 [updated 2024 March 24; 2025 Oct 30]. Available from: <https://www.cdc.gov/niosh/ergonomics/ergo-programs/risk-factors.html>.
46. The Danish Working Environment Authority. Pas på kroppen [Internet]. 2025 [Available from: <https://at.dk/faa-viden/fysisk-arbejde/pas-paa-kroppen-i-fysisk-arbejde/>].
47. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: A review of surgical ergonomics literature and development of educational illustrations. *Am J Surg.* 2023.
48. Pierce SM, Heiman AJ, Ricci JA. Evaluating the Current State of Ergonomics Education Offered to Students in US Medical Students. *Am Surg.* 2023;89(5):1798-806.

49. Epstein S, Tran BN, Capone AC, Ruan QZ, Fukudome EY, Ricci JA, et al. The Current State of Surgical Ergonomics Education in U.S. Surgical Training: A Survey Study. *Ann Surg.* 2019;269(4):778-84.
50. Jensen MJ, Liao J, Van Gorp B, Sugg SL, Shelton J, Corwin C, et al. Incorporating Surgical Ergonomics Education into Surgical Residency Curriculum. *J Surg Educ.* 2021;78(4):1209-15.
51. Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics Workshop Improves Musculoskeletal Symptoms in General Surgery Residents. *J Surg Res.* 2022;280:567-74.
52. Winters JN, Sommer NZ, Romanelli MR, Marschik C, Hulcher L, Cutler BJ. Stretching and Strength Training to Improve Postural Ergonomics and Endurance in the Operating Room. *Plast Reconstr Surg Glob Open.* 2020;8(5):e2810.
53. Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg.* 2010;210(3):306-13.
54. Szeto GPY, Cheng SWK, Poon JTC, Ting ACW, Tsang RCC, Ho P. Surgeons' Static Posture and Movement Repetitions in Open and Laparoscopic Surgery. *J Surg Res.* 2012;172(1):e19-e31.
55. Andersen LL, Kjær M, Søgaard K, Hansen L, Kryger AI, Sjøgaard G. Effect of two contrasting types of physical exercise on chronic neck muscle pain. *Arthritis Rheum.* 2008;59(1):84-91.
56. Sjøgaard G, Justesen JB, Murray M, Dalager T, Søgaard K. A conceptual model for worksite intelligent physical exercise training - IPET - intervention for decreasing life style health risk indicators among employees: a randomized controlled trial. *BMC Public Health.* 2014;14(1):652.
57. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334-59.
58. Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. *Cochrane Database Syst Rev.* 2017(4).
59. Rogoff HM, Byrnes YM, Kauffman CA. Importance of Exercise for Career Longevity: Maintaining Fitness, Strength, and Flexibility as a Plastic Surgeon. *Plast Reconstr Surg Glob Open.* 2025;13(1):e6439.
60. Tejirian T. Surgery Is a Contact Sport: A Guide on Injury Prevention for Surgeons 2021 [Available from: <https://www.generalsurgerynews.com/Opinion/Article/09-21/Surgery-Is-a-Contact-Sport/64653>].
61. Dairywala MI, Gupta S, Salna M, Nguyen TC. Surgeon Strength: Ergonomics and Strength Training in Cardiothoracic Surgery. *Semin Thorac Cardiovasc Surg.* 2022;34(4):1220-9.
62. Sjøgaard G, Christensen JR, Justesen JB, Murray M, Dalager T, Fredslund GH, et al. Exercise is more than medicine: The working age population's well-being and productivity. *J Sport Health Sci.* 2016;5(2):159-65.

63. Kaergaard A, Andersen JH, Rasmussen K, Mikkelsen S. Identification of neck-shoulder disorders in a 1 year follow-up study. Validation of a questionnaire-based method. *Pain (Amsterdam)*. 2000;86(3):305-10.
64. Dworkin RH, Turk DC, Wyrwich KW, Beaton D, Cleeland CS, Farrar JT, et al. Interpreting the Clinical Importance of Treatment Outcomes in Chronic Pain Clinical Trials: IMMPACT Recommendations. *J Pain*. 2008;9(2):105-21.
65. Andersen CH, Andersen LL, Pedersen MT, Mortensen P, Karstad K, Mortensen OS, et al. Dose-Response of Strengthening Exercise for Treatment of Severe Neck Pain in Women. *J Strength Cond Res*. 2013;27(12):3322-8.
66. Pedersen MT, Andersen LL, Jørgensen MB, Søgaard K, Sjøgaard G. Effect of Specific Resistance Training on Musculoskeletal Pain Symptoms: Dose-Response Relationship. *J Strength Cond Res*. 2013;27(1):229-35.
67. Göras C, Olin K, Unbeck M, Pukk-Härenstam K, Ehrenberg A, Tessma MK, et al. Tasks, multitasking and interruptions among the surgical team in an operating room: a prospective observational study. *BMJ Open*. 2019;9(5):e026410.
68. Shahrezaei A, Sohani M, Taherkhani S, Zarghami SY. The impact of surgical simulation and training technologies on general surgery education. *BMC Med Educ*. 2024;24(1):1297.
69. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52(6):377-84.
70. Nelson E, Kelly D, Ni Bhriain O, Garry F, Clifford AM, Allardyce JM. The effectiveness of community dance in people with cancer: a mixed-methods systematic review and meta-analysis. *Health Promot Int*. 2023;38(4).
71. Hooper P, Jutai JW, Strong G, Russell-Minda E. Age-related macular degeneration and low-vision rehabilitation: a systematic review. *Can J Ophthalmol*. 2008;43(2):180-7.
72. Silverman SR, Schertz LA, Yuen HK, Lowman JD, Bickel CS. Systematic review of the methodological quality and outcome measures utilized in exercise interventions for adults with spinal cord injury. *Spinal Cord*. 2012;50(10):718-27.
73. Giagio S, Volpe G, Pillastrini P, Gasparre G, Frizziero A, Squizzato F. A Preventive Program for Work-related Musculoskeletal Disorders Among Surgeons: Outcomes of a Randomized Controlled Clinical Trial. *Ann Surg*. 2019;270(6):969-75.
74. Franasia J, Craven R, Mosaly P, Gehrig PA. Feasibility and acceptance of a robotic surgery ergonomic training program. *JSLs*. 2014;18(4).
75. Hess P, Athanasiadis D, Lee NK, Monfared S, Cleveland PM, Stefanidis D. Preventing Surgeon Work-Related Musculoskeletal Disorders: A Pilot Study of the Comprehensive Operating Room Ergonomics (CORE) Program. *Am J Occup Ther*. 2024;78(5).
76. Yadav SK, Lal G, Jain SB, Jha CK, Corwin C, Van Gorp B, et al. Indian surgery Trainee's perspective on surgical ergonomics principles and education: A long road ahead. *Am J Surg*. 2023;226(5):735-40.
77. Kromberg LS, Kildebro NV, Mortensen LQ, Amirian I, Rosenberg J. Microbreaks in Laparoscopic Appendectomy have No Effect on Surgeons' Performance and Well-being. *J Surg Res*. 2020;251:1-5.

78. Dorion D, Darveau S. Do micropauses prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. *Ann Surg.* 2013;257(2):256-9.
79. Engelman C, Schneider M, Kirschbaum C, Grote G, Dingemann J, Schoof S, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: A randomized clinical trial. *Surg Endosc.* 2011;25(4):1245-50.
80. Veelen MA, Jakimowicz JJ, Goossens RH, Meijer DW, Bussmann JB. Evaluation of the usability of two types of image display systems, during laparoscopy. *Surg Endosc.* 2002;16(4):674-8.
81. Lim AK, Ryu J, Yoon HM, Yang HC, Kim S-K. Ergonomic effects of medical augmented reality glasses in video-assisted surgery. *Surgical endoscopy.* 2022;36(2):988-98.
82. Hokenstad ED, Hallbeck MS, Lowndes BR, Morrow MM, Weaver AL, McGree M, et al. Ergonomic Robotic Console Configuration in Gynecologic Surgery: An Interventional Study. *J Minim Invasive Gynecol.* 2021;28(4):850-9.
83. Chan C, Tan YC, Lim EW, Teo JY, Lin J, Tan WJ, et al. Evaluating the surgical trainee ergonomic experience during minimally invasive abdominal surgery (ESTEEMA study). *Sci Rep.* 2024;14(1):12502.
84. Klein M, Andersen LPH, Alamili M, Gogenur I, Rosenberg J. Psychological and physical stress in surgeons operating in a standard or modern operating room. *Surg Laparosc Endosc Percutan Tech.* 2010;20(4):237-42.
85. van Det MJ, Meijerink WJ, Hoff C, van Veelen MA, Pierie JP. Ergonomic assessment of neck posture in the minimally invasive surgery suite during laparoscopic cholecystectomy. *Surg Endosc.* 2008;22(11):2421-7.
86. Cha JS, Athanasiadis DI, Asadi H, Stefanidis D, Nussbaum MA, Yu D. Evaluation of a passive arm-support exoskeleton for surgical team members: Results from live surgeries. *Journal of safety research.* 2024;89:322-30.
87. Kawahira H, Nakamura R, Shimomura Y, Oshiro T, Okazumi S, Lefor AK. A wearable lower extremity support for laparoscopic surgeons: A pilot study. *Asian J Endosc Surg.* 2021;14(1):144-8.
88. Liu S, Hemming D, Luo RB, Reynolds J, Delong JC, Sandler BJ, et al. Solving the surgeon ergonomic crisis with surgical exosuit. *Surg Endosc.* 2018;32(1):236-44.
89. Nishimoto W, Kawahira H, Shimomura Y, Nishizawa Y, Ito M. A standing posture support device that reduces laparoscopic surgeons' occupational lower limb stress. *Minim Invasive Ther Allied Technol.* 2019;28(3):151-6.
90. Dalager T, Jensen PT, Winther TS, Savarimuthu TR, Markauskas A, Mogensen O, et al. Surgeons' muscle load during robotic-assisted laparoscopy performed with a regular office chair and the preferred of two ergonomic chairs: A pilot study. *Appl Ergon.* 2019;78:286-92.
91. Haramis G, Rosales JC, Okhunov Z, Mues AC, Badani K, Gupta M, et al. Prospective randomized evaluation of foot gel pads for operating room staff comfort during laparoscopic renal surgery. *Journal of Urology.* 2010;183(4 SUPPL. 1):e424.
92. Kraemer B, Seibt R, Stoffels AK, Rothmund R, Brucker SY, Rieger MA, et al. An ergonomic field study to evaluate the effects of a rotatable handle piece on muscular stress and fatigue as well as subjective ratings of usability, wrist posture and precision

- during laparoscopic surgery: an explorative pilot study. *Int Arch Occup Environ Health*. 2018;91(8):1021-9.
93. Rassweiler J, Goezen AS, Jalal A, Klein J, Hruza M, Schulze M. A new platform improving ergonomics of laparoscopic surgery: Experimental studies and initial clinical evaluation. *Journal of Urology*. 2012;187(4 SUPPL. 1):e347.
 94. Unver S, Makal Organ E. The effect of anti-fatigue floor mat on pain and fatigue levels of surgical team members: A crossover study. *Appl Ergon*. 2023;110:104017.
 95. Christiansen HJ, Sandal LF, Mogensen O, Norasi H, Chrouser K, Hallbeck MS, et al. Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA). *Trials*. 2025;26(1):565.
 96. Michie S, Atkins L, West R. *The Behaviour Change Wheel: A Guide to Designing Interventions*: Silverback Publishing; 2014.
 97. Michie S, van Stralen MM, West R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Sci*. 2011;6(1):42-.
 98. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon*. 1987;18(3):233-7.
 99. Dalager T, Sjöberg LM, Hansen AF, Sjøgaard G, Søgaard K. Afrapportering på "Intelligent Motion implementering i dagligdagen". https://www.sdu.dk/-/media/files/forskning/forskningsformidling/citizen_science/intelligent-motion-implementering-i-dagligdagen_fuld-rapport.pdf: University of Southern Denmark, Research unit of Physical Activity and Health in Working Life; 2024.
 100. Borg GAV. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-81.
 101. Dalager T, Bredahl TG, Pedersen MT, Boyle E, Andersen LL, Sjøgaard G. Does training frequency and supervision affect compliance, performance and muscular health? A cluster randomized controlled trial. *Man Ther*. 2015;20(5):657-65.
 102. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. *J Clin Nurs*. 2005;14(7):798-804.
 103. Ware JE, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Med Care*. 1996;34(3):220-33.
 104. Kristensen TS, Borritz M, Villadsen E, Christensen KB. The Copenhagen Burnout Inventory: A new tool for the assessment of burnout. *Work Stress*. 2005;19(3):192-207.
 105. Ilmarinen J. The Work Ability Index (WAI). *Occupational Medicine*. 2007;57(2):160-.
 106. Grimby G, Börjesson M, Jonsdottir IH, Schnohr P, Thelle DS, Saltin B. The "Saltin-Grimby Physical Activity Level Scale" and its application to health research. *Scand J Med Sci Sports*. 2015;25 Suppl 4:119-25.
 107. Strøyer J, Essendrop M, Jensen LD, Warming S, Avlund K, Schibye B. Validity and reliability of self-assessed physical fitness using visual analogue scales. *Percept Mot Skills*. 2007;104(2):519-33.
 108. Statens Institut for Folkesundhed SU. Spørgeskema: Hvordan har du det? 2021 Odense (DK): Syddansk Universitet; 2021 [Available from:

https://regionsyddanmark.dk/media/yytpvb01/sp%C3%B8rgeskema-sundhedsprofilen-2021.pdf?utm_source=chatgpt.com.

109. StataCorp. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC; 2021.
110. Danish Working Environment Authority (Arbejdstilsynet). Assessment of working positions and movements 1998 [Available from: <https://at.dk/en/regulations/guidelines/assessment-of-working-positions-and-movements/>.
111. Vasireddi N, Shah AK, Moyal AJ, Gausden EB, McLawhorn AS, Poelstra KA, et al. High Prevalence of Work-related Musculoskeletal Disorders and Limited Evidence-based Ergonomics in Orthopaedic Surgery: A Systematic Review. *Clin Orthop Relat Res*. 2024;482(4):659-71.
112. El Boghdady M, Ewalds-Kvist BM. General surgeons' occupational musculoskeletal injuries: A systematic review. *The Surgeon*. 2024;22(6):322-31.
113. Short C, Basuino M, Segalini N, Rialon KL, Brandt ML. Working Through the Pain: Surgical Culture and Musculoskeletal Injury. *Curr Surg Rep*. 2021;9(7):18.
114. Schluskel AT, Maykel JA. Ergonomics and Musculoskeletal Health of the Surgeon. *Clin Colon Rectal Surg*. 2019;32(6):424-34.
115. Shariat A, Cleland JA, Danaee M, Kargarfard M, Sangelaji B, Tamrin SBM. Effects of stretching exercise training and ergonomic modifications on musculoskeletal discomforts of office workers: a randomized controlled trial. *Braz J Phys Ther*. 2018;22(2):144-53.
116. Johnston V, Chen X, Welch A, Sjøgaard G, Comans TA, McStea M, et al. A cluster-randomized trial of workplace ergonomics and neck-specific exercise versus ergonomics and health promotion for office workers to manage neck pain – a secondary outcome analysis. *BMC Musculoskelet Disord*. 2021;22(1):68-12.
117. Yazdani A, Wells R. Barriers for implementation of successful change to prevent musculoskeletal disorders and how to systematically address them. *Appl Ergon*. 2018;73:122-40.
118. Gabrielson AT, Mukherjee A, Alam F, Hallet J. Incorporating ergonomics into surgical checklist workflows. *Am J Surg*. 2025;247:116281.
119. Hansen AF, Hasle P, Caroly S, Reinhold K, Järvis M, Herrig AO, et al. Participatory ergonomics: What works for whom and why? A realist review. *Ergonomics*. 2024;67(1):13-33.
120. Graham V, Arora B. Women in surgery: trends in nine surgical specialties. *ANZ J Surg*. 2023;93(10):2344-9.
121. Hirani R, Anderson-Crannage M, Goldberg C, Lodescar RJ, Etienne M. Gender Disparity Trends in Surgical Specialties: A 12-Year Analysis. *J Surg Res*. 2025;316:151-7.
122. Newman TH, Parry MG, Zakeri R, Pegna V, Nagle A, Bhatti F, et al. Gender diversity in UK surgical specialties: a national observational study. *BMJ Open*. 2022;12(2):e055516.
123. Dalager T, Welch A, O'Leary SP, Johnston V, Sjøgaard G. Clinically Relevant Decreases in Neck/Shoulder Pain Among Office Workers Are Associated With Strength Training Adherence and Exercise Compliance: Explorative Analyses From a Randomized Controlled Trial. *Phys Ther*. 2023;103(2):1.
124. Murray M, Lange B, Nørnberg BR, Søgaard K, Sjøgaard G. Self-administered physical exercise training as treatment of neck and shoulder pain among military helicopter pilots and crew: a randomized controlled trial. *BMC Musculoskelet Disord*. 2017;18(1):147-11.

125. Dalager T, Sjøgaard G, Justesen JB, Steele J. Intelligent Physical Exercise Training in a Workplace Setting Improves Muscle Strength and Musculoskeletal Pain: A Randomized Controlled Trial. *Biomed Res Int*. 2017;2017(2017):1-9.
126. Sundstrup E, Seeberg KGV, Bengtsen E, Andersen LL. A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work. *J Occup Rehabil*. 2020;30(4):588-612.
127. McDermott J, Lum SS, de Virgilio C. Finding Time and Energy to Exercise—5 Tips for Surgeons. *JAMA Surg*. 2025;160(2):122-4.
128. Nielsen SG, Prins JL, Pedersen M, Saervoll CA, Molsted S. Little room for maneuvering: hospital managers' perspectives on integration of physical exercise during working hours. A qualitative investigation in a grounded theory design. *J Public Health*. 2024.
129. Pultz CJ, Lohse TM, Justesen JB, Særvoll CA, Møller SF, Lindegaard B, et al. Implementation of Intelligent Physical Exercise Training at a Danish Hospital—A Qualitative Study of Employees' Barriers and Facilitators for Participation. *Int J Environ Res Public Health*. 2023;20(22):7085.
130. Dalager T, Hojmark A, Jensen PT, Sogaard K, Andersen LN. Using an intervention mapping approach to develop prevention and rehabilitation strategies for musculoskeletal pain among surgeons. *BMC Public Health*. 2019;19(1):320.
131. Bredahl TVG, Særvoll CA, Kirkelund L, Sjøgaard G, Andersen LL. When Intervention Meets Organisation, a Qualitative Study of Motivation and Barriers to Physical Exercise at the Workplace. *ScientificWorldJournal*. 2015;2015.
132. Chrouser K, Kim FJ, Smith A, Stoffel JT, Goldenberg M. Optimizing Outcomes in Urologic Surgery: Intraoperative Environmental, Behavioral, and Performance Considerations. *Urol Pract*. 2020;7(5):405-12.
133. Razavi S, De EJB. Ergonomics in Urology: Silent Contributor to Burnout Among Women in Urology? *Urology*. 2023;173:222-5.
134. Otukoya EZ, Amiri A, Alimohammadi E. Surgeon well-being: a systematic review of stressors, mental health, and resilience. *BMC Surg*. 2025;25(1):430.
135. Sedgwick P. Non-response bias versus response bias. *BMJ (Online)*. 2014;348(apr09 1):g2573-g.
136. Jordan S, Watkins A, Storey M, Allen SJ, Brooks CJ, Garaiova I, et al. Volunteer Bias in Recruitment, Retention, and Blood Sample Donation in a Randomised Controlled Trial Involving Mothers and Their Children at Six Months and Two Years: A Longitudinal Analysis. *PLoS One*. 2013;8(7):e67912.
137. Hilt L, Sherman B, Tan WH, Lak K, Gould JC, Kindel TL, et al. Bariatric Surgeon Ergonomics: A Comparison of Laparoscopy and Robotics. *J Surg Res*. 2024;295:864-73.
138. Andersen LL, Saervoll CA, Mortensen OS, Poulsen OM, Hannerz H, Zebis MK. Effectiveness of small daily amounts of progressive resistance training for frequent neck/shoulder pain: randomised controlled trial. *Pain®*. 2011;152(2):440-6.
139. Justesen JB, Sogaard K, Dalager T, Christensen JR, Sjøgaard G. The Effect of Intelligent Physical Exercise Training on Sickness Presenteeism and Absenteeism Among Office Workers. *J Occup Environ Med*. 2017;59(10):942-8.
140. Schinke SP. Prevention science and practice: An agenda for action. *J Prim Prev*. 1994;15(1):45-57.

PAPER I – SYSTEMATIC REVIEW

Systematic review of applied ergonomics in pelvic and abdominal surgery on surgeon musculoskeletal health

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ABSTRACT

Objectives

The objective of this systematic review was to synthesize evidence on ergonomic interventions in the OR and to assess the association with musculoskeletal health and workload among gynecologic, urologic, and colorectal surgeons.

Design

This systematic review was registered in PROSPERO (CRD42022354609), reported per PRISMA guidelines.

Data sources

Medline, Embase, and CENTRAL from inception through July 2024.

Eligibility criteria

Eligible studies evaluated ergonomic interventions applied during live gynecologic, urologic, or colorectal surgeries - performed via open, robot-assisted, or conventional laparoscopic techniques - and reported outcomes related to MSP or physical workload. Studies with pre-post intervention outcome measurements.

Data extraction and synthesis

Data was independently extracted by two reviewers, and a narrative synthesis was performed due to heterogeneity. Both statistically significant and non-significant results were extracted and included in the synthesis. Methodological quality was assessed with the Downs and Black checklist.

Results

Of 6,776 records screened, 25 studies met inclusion criteria. Interventions were categorized into five types: ergonomic education, microbreaks, posture optimization, body support devices, and miscellaneous ergonomic devices. Microbreaks, posture optimization, and ergonomic education were most consistently associated with reductions in MSP and improvements in posture and workload. One study was an RCT, and most had small sample sizes, short intervention duration and methodological limitations, including heterogeneity in design, outcome definitions, and measurement methods. Outcomes were predominantly self-reported (questionnaires, VAS/NRS), with a subset of studies using objective measures (EMG, postural analysis) or observer assessments (RULA/REBA).

Conclusion

Low-cost, accessible ergonomic strategies, particularly microbreaks, posture optimization, and ergonomic education show promise in reducing musculoskeletal symptoms and workload. However, the methodological quality of the included studies warrants cautious interpretation, and evidence of

effectiveness remains limited. Further high-quality research is needed to establish effectiveness and inform practical implementation in the OR setting.

Keywords Surgical Ergonomics, Musculoskeletal Pain, Ergonomic Intervention, Workload

Article Summary

Strengths and Limitations of This Study

- Highlights how ergonomic interventions may contribute to improved musculoskeletal health among abdominal and pelvic surgeons.
- Includes interventions conducted in actual surgical environments rather than simulation-based settings.
- The evidence synthesis is limited by substantial heterogeneity in study designs, interventions, outcomes and their assessment methods, as well as a moderate to high risk of bias across the included studies.

INTRODUCTION

Musculoskeletal disorders (MSDs) are the most prevalent work-related health problem in the EU, with musculoskeletal pain (MSP) the common symptom [1], not just in traditionally physically demanding jobs such as construction and agriculture [1]. MSP is also highly prevalent among surgeons, with reported rates ranging from 35% to 93% across various specialties [2-4]. Abdominal and pelvic surgeons are no exception - a 3-month multi-site pain prevalence of 71% has been reported, with the neck, shoulders, low back and wrists as the most commonly affected regions [4-6]. Gynecologic, urologic, and colorectal surgeons share several ergonomic exposures, particularly during minimally invasive surgery (MIS). These include prolonged static and awkward postures, repetitive instrument handling, restricted freedom of movement, reduced dexterity, and reliance on indirect visual feedback from monitors [7-9].

The consequences of MSP extend beyond fatigue and physical discomfort in the operating room (OR). MSP also negatively affects sleep, leisure activities [4, 10], and shortens career longevity [2, 10]. These consequences raise broader societal concerns, especially in the context of the estimated future surgeon shortages and the potential impact on patient access to surgical care [11-13]. Further, muscular fatigue and chronic MSP may compromise surgical performance and potentially impact patient safety [14, 15].

Numerous occupational risk factors for developing MSP in surgery have been identified over time [16, 17], including repetitive movements, static and awkward postures, and high demands for precision and time.

In response, the past decade has seen rise in studies aimed at mitigating ergonomic risks and reducing physical strain [18-23]. Some studies have compared physical demands and workload across surgical modalities; however, no single modality has demonstrated clear superiority in preventing MSP [19, 24-26]. Instead, each modality tends to shift musculoskeletal strain to different regions rather than mitigating it entirely. Ergonomic interventions have been explored in both simulation-based and actual OR settings, however these environments differ significantly in ways that matter for interpreting intervention effects. In simulation, the absence of real patient safety demands, time pressure, and physical fatigue may not reflect the real ergonomic conditions under which surgeons actually work. In actual surgical practice, surgeons often push through discomfort and overlook signs of fatigue without reporting them [27, 28], underscoring the importance of evaluating ergonomic interventions under authentic OR conditions. Despite this growing literature, no systematic review has restricted inclusion to interventions evaluated exclusively in live OR settings across gynecologic, urologic, and colorectal surgery. The extent to which such ergonomic

interventions reduce MSP and physical workload in this context therefore remains uncertain [2, 6, 20].

The objective of this systematic review is to synthesize existing evidence on the association between ergonomic interventions applied in the OR on outcomes of musculoskeletal health and musculoskeletal workload among abdominal and pelvic surgeons.

METHODS

This systematic review was registered at PROSPERO (CRD42022354609), and the reporting follows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [29]. A protocol has not been published.

Information Sources and Search Strategy

A comprehensive search was conducted across Medline, Embase (Ovid), and the Cochrane Central Register of Controlled Trials (CENTRAL) from the inception of each database up to July 2022, with an update performed in July 2024. The search strategy utilized a combination of Medical Subject Headings (MeSH) and relevant keywords related to surgical ergonomics in the OR (Appendix A). Search terms were developed with input from a research librarian specializing in work physiology, based on a thorough review of titles, abstracts, and keywords from key studies. Systematic and standard reviews identified in the search and not eligible for inclusion were reviewed to identify additional relevant references.

Study Selection and Eligibility Criteria

The literature search results were managed using Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Screening was independently conducted by two reviewers (HJC and either HN or ET), who first assessed the titles and abstracts of all retrieved records. This was followed by full-text screening using the same approach. In cases of disagreement, a third reviewer (HN or ET) was consulted to reach consensus. Reasons for excluding studies were documented throughout the process. None of the review authors were blinded to journal titles, study authors, or institutions.

All original studies written in English that met the following criteria based on the PICOS framework (Participants, Intervention, Comparison, Outcome and Study design) were included:

- **Participants:** Eligible studies included residents, fellows, and attending surgeons performing urological, gynecological, colorectal- or general abdominal surgery. Studies with mixed surgical specialties were included only if all other eligibility criteria were met.

- **Interventions:** Studies were included if they evaluated ergonomic interventions applied during real surgery in the OR, including open surgery, robot-assisted or conventional laparoscopy, excluding microsurgery, endoscopic procedures, and vaginal-access surgery. Ergonomic interventions were defined as any strategies aimed at improving or evaluating the physical ergonomics during live surgical procedures, excluding those interventions solely conducted during training or simulations.
- **Outcomes:** Studies were included if they assessed outcomes related to musculoskeletal health or physical workload. These included self-reported measurements (e.g. body part discomfort severity), objective measurements (e.g. muscle activity data obtained with electromyography (EMG)), and observer assessments (e.g. postural analysis using the Rapid Upper Limb Assessment (RULA) (2)).
- **Study Design:** Both experimental and observational studies were eligible, provided they included pre-post intervention assessments.

Data Extraction and Synthesis of Results

Three authors (HJC, HM, and ET) independently extracted data from the eligible studies, including the following items: author and year of publication, country, surgical specialty, surgical approach, number of participants, study design, intervention characteristics, and any reported outcomes and effect estimates related to musculoskeletal health and workload. When studies reported outcomes at multiple time points, data were extracted for baseline and the primary follow-up time point. Studies were categorized according to their primary intervention component, and Tables 2-6 were structured accordingly, with studies listed in alphabetical order by the first author's last name. Studies were categorized as 'ergonomic education' when the intervention consisted of structured educational sessions or workshops delivering ergonomic knowledge or training. This was distinguished from interventions such as microbreaks, posture optimization, and ergonomic devices, where the ergonomic intervention was directly assessed in the OR.

Findings related to musculoskeletal health and workload, including measures that favored the intervention, showed no clear effect, or were mixed. Statistical synthesis was not considered possible or appropriate, due to heterogeneity of outcomes and effect measures. No assumptions were made about any missing or unclear information.

Assessment of methodological quality

Two authors (HJC and either ET, HN, KC, MSH, PJ, or TD) independently assessed the methodological quality at the study level using the Downs and Black checklist, which is applicable to both randomized and non-randomized study designs. With good validity and reliability [30], this

checklist consists of 27 questions across four domains: reporting, external validity, internal validity (bias and confounding), and power. Each question is scored from zero to two points, with a maximum score of 28 for randomized controlled trials and 25 for non-randomized studies. Higher scores indicate a lower risk of bias. Studies were classified based on their scores as follows: excellent (26–28), good (20–25), fair (15–19), and poor (≤ 14) [31–33]. Any disagreements among authors were resolved through discussion. To aid interpretability, the median D&B score is reported for each intervention category. These scores are used to contextualize the strength of evidence within each category.

The GRADE approach was not applied, as the substantial heterogeneity in outcome definitions and measurement methods across included studies precluded meaningful assessment of the certainty of evidence at the outcome level [34].

Patient and Public Involvement statement

None

RESULTS

The database search yielded 6,776 unique records that were screened by title and abstracts, leading to the review of 210 full-text papers. Ultimately, 25 studies were included in the synthesis (Fig. 1). A list of excluded studies that might appear to meet the inclusion criteria, but which were excluded can be found in Appendix B.

Study Characteristics

Table 1 provides an overview of included studies. With one exception, all were observational in design and demonstrated considerable heterogeneity. Among them were seven pilot studies [35–41] and two feasibility studies [42, 43]. Sample sizes varied widely, ranging from individual surgeon measurements to 141 participants in a cluster randomized controlled trial. Geographically, the studies were conducted across North America ($n = 10$), Europe ($n = 9$), and Asia ($n = 6$).

The studies were categorized by their primary intervention component: six studies focused on ergonomic education [35, 40, 43–46] (Table 2). Another four studies explored the impact of intra-operative microbreaks, with or without stretching exercises [10, 15, 47, 48] (Table 3). Six studies investigated OR posture optimization [41, 49–53] (Table 4), and four studies investigated the impact of body support devices [37, 39, 42, 54] (Table 5). Five studies investigated miscellaneous

ergonomic devices [36, 38, 55-57] (Table 6). Several studies included overlapping intervention elements, e.g. ergonomic education often incorporated guidance on working posture and the use of microbreaks [35, 44-46, 53].

FIGURE 1

Table 1 – Summary of Study Characteristics

Author	Year	Country	Study design	No. of participants	Surgical specialty	Main intervention component	Methodological concerns	Downs and Black (D&B) category
Cha	2024	USA	Case-crossover	n= 7	General	Body support devices	Possible selection bias. Possible confounders not addressed.	Fair
Kawahira	2021	Japan	Case-crossover	n= 3	General	Body support devices	Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Poor
Liu	2018	USA	Case-crossover	n= 7	General	Body support devices	Inadequate participant characteristics. Inconsistent reporting. Possible selection bias.	Fair
Nishimoto	2019	Japan	Case-crossover	n= 5	Colorectal	Body support devices	Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Fair
Allespach	2020	USA	Pre-post study	Module 1: n= 36 Module 2: n= 18 Module 3: n= 15	General	Ergonomic Education	Loss to follow-up. Inconsistent reporting. Inadequate participant characteristics. Possible selection bias. Possible confounders not addressed.	Poor
Cerier	2022	USA	Pre-post study	Pre-workshop survey: n= 33 Ergonomic workshop:	General	Ergonomic Education	Loss to follow-up. Possible selection bias. Possible	Fair

				n= 22 Post-workshop survey: n= 22			confounders not addressed.	
Franasiak	2014	USA	Pre-post study	Pre-intervention survey: n= 42 Personalized session: n= 32 Post-intervention survey: n= 37	Combination	Ergonomic Education	Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Fair
Giagio	2019	Italy	Cluster randomized controlled trial	n= 141	Combination	Ergonomic Education	Multiple comparisons.	Good
Hess	2024	USA	Case-crossover	n= 6	General	Ergonomic Education	Limited external validity. Possible selection bias.	Fair
Yadav	2023	India	Pre-post study	Pre-webinar survey: n= 71 Webinar: n= 46 Post-webinar survey: n= 46 2-month post-webinar survey: n= 34	General	Ergonomic Education	Loss to follow-up. Possible selection bias.	Fair
Dorion	2013	Canada	Case-crossover	n= 16	Combination	Microbreaks	Inadequate participant characteristics. Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Poor
Engelmann	2011	Germany	Case-crossover	n= 7	General	Microbreaks	Inadequate participant characteristics. Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Fair
Hallbeck	2017	USA	Case-crossover	n= 56	Combination	Microbreaks	Inconsistent reporting. Possible selection bias.	Fair

Kromberg	2020	Denmark	Case-crossover	n= 12	General	Microbreaks	Inadequate participant characteristics. Possible selection bias.	Good
Dalager	2019	Denmark	Case-crossover	n= 6	Gynecology	Misc. Ergonomic Devices	Possible selection bias.	Fair
Haramis	2010	USA	Case-crossover	n= 18	Urology	Misc. Ergonomic Devices	Possible selection bias. Possible confounders not addressed.	Fair
Kraemer	2018	Germany	Case-crossover	n= 11	Gynecology	Misc. Ergonomic Devices	Possible selection bias.	Fair
Rassweiler	2012	Germany	Case-crossover	n= 1	Urology	Misc. Ergonomic Devices	Inconsistent reporting. Possible selection bias. Possible confounders not addressed.	Poor
Unver	2023	Turkey	Case-crossover	n= 38	Combination	Misc. Ergonomic Devices	Possible selection bias.	Good
Chan	2024	Singapore	Pre-post study	Phase 1: n= 46 Phase 2: n= 64	General	OR posture optimization	Limited external validity. Possible selection bias.	Fair
Hokenstad	2021	USA	Case-crossover	n= 6	Gynecology	OR posture optimization	Possible selection bias. Possible confounders not addressed.	Fair
Klein	2010	Denmark	Case-crossover	n= 10	General	OR posture optimization	Possible selection bias. Possible confounders not addressed.	Fair
Lim	2022	South Korea	Case-crossover	n= 3	Combination	OR posture optimization	Inadequate participant characteristics. Possible selection bias. Possible confounders not addressed.	Fair
vanDet	2008	The Netherlands	Case-crossover	n= 32	General	OR posture optimization	Inadequate participant characteristics. Possible selection bias. Possible confounders not addressed.	Fair

Veelen	2002	Netherlands	Case-crossover	n= 12	General	OR posture optimization	Inadequate participant characteristics. Possible selection bias. Possible confounders not addressed.	Fair
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Pre-post study: a study in which outcomes are measured in the same participants before and after an intervention; Case-crossover: a study in which each participant serves as their own control across two conditions.

Ergonomic Education

Study characteristics and methodological quality

Table 2 provides an overview of six studies; one cluster randomized controlled trial (RCT) and five pre-post studies that investigated the association of ergonomic education on various outcomes [35, 40, 43-46]. The duration and the follow-up of these interventions ranged, as did the content and delivery modes. These studies included participant groups ranging from six to 141 individuals, predominantly consisting of surgeons and residents in general surgery, urology, and gynecology, however, ear, nose and throat surgeons [58], and orthopedic, vascular, thoracic, plastic, cardiac, maxillofacial, pediatric, otorhinolaryngology and neurosurgery surgeons are also represented [44]. Outcomes were self-reported or observer assessments.

The median D&B score across these studies was 15.5 (range 10–23), indicating overall fair methodological quality. This rating largely reflects that most studies used pre-post designs without a control group, and often with small sample sizes in pilot or feasibility studies [35, 40, 43] with objectives other than assessing the effect of an intervention. Only one study was a cluster RCT [44], and this was the only study reported to be adequately powered. Only one study [44] used allocation concealment (opaque sealed envelopes) for cluster randomization.

Outcomes

Four pre-post studies [35, 43, 45, 46] incorporated ergonomic lectures into the existing training of surgical residents. All lectures were delivered by ergonomics or occupational health professionals. These interventions started with attending ergonomic lectures followed by practicing the ergonomic principles in the OR for a period of two to twelve months. One pilot-study offered three lectures [35], while another study offered a single lecture with an optional 15 min. personalized ergonomics session [45]. A third feasibility study offered a slideshow lecture and an optional 5-min. session personalized ergonomics session [43], and the fourth study offered two online webinars [46]. In these four studies, however, participants reported a reduction in their musculoskeletal discomfort or symptoms, with improvements reported by 74 to 85% of participants following the ergonomic lectures. One study specifically reported a significant reduction of MSP from pre- to post- lecture

[45]. These findings are supported by one experimental study [44] that investigated the effect of instructions in surgical ergonomic principles, combined with pre-post-surgery stretching exercises, over a period of six months. At the six months follow-up, the intervention group had a significantly lower prevalence (72% vs. 53%) of low-back pain compared to the control group. No significant between-group differences were observed for any other body region, although there was a trend towards lower MSP intensity in the intervention group.

One mixed-method pre-post study offered multi-modal educational content including educational lectures and weekly live in-person or virtual coaching with an occupational therapist [40]. This study reported on improved observer-reported posture among participants, but no significant change in MSP in the neck and shoulder region; however, the head, back, and fingers did change, indicating increased MSP and discomfort.

Table 2 Ergonomic Education

Author	No. of participants	Study design	Modality	Intervention details	Outcome type and measurement (tool)	Results	D&B score
Allespach	Pre-lecture survey: n= 36. Post-lecture 1 & 2: n= 18. Post-lecture 3: n= 15.	Pre-post study	Unknown	Surgical residents were offered three 1-hour lectures which covered the importance of posture, OR ergonomics, microbreaks and stretches for the neck, low back, shoulders and arms. The lectures were led by physical therapists.	Self-reported outcome: Body part musculoskeletal pain (MSP) (0-10 NRS) and proportion (%). Pre- and post-lecture assessments over the course of one academic year using questionnaires.	No significant difference in MSP intensity. Eighty-five percent (n= 13) those who attended the third module and applied MB and stretches in the OR reported a decrease in MSP, especially in the areas of the cervical and lumbar spine.	10
Cerier	Baseline survey: n= 33. Ergonomic workshop: n= 22. Four-months follow-up: n= 22.	Pre-post study	Unknown	Surgical residents were offered one 1-hour lecture on surgical ergonomics which covered the importance of working posture, and guidance on ergonomic posture and microbreaks in the OR, followed by a	Self-reported outcome: Body part MSP (1-10 Likert scale), proportion (%) and other symptoms (including eye strain, numbness/tingling, stiffness, and muscle fatigue). Pre- and post assessments were obtained four months apart	A significant decrease in MSP intensity post the surgical ergonomics education workshop compared to pre-workshop. Eighty two percent (n= 18) of participants reported an improvement in their symptom severity or frequency.	19

				15-minute personalized ergonomics coaching session.	using questionnaires.	No significant decrease in the proportion of participants who experience improvements in other symptoms.	
				The sessions were conducted by physical medicine and rehabilitation faculty and fellows during grand rounds.			
Franasiak	Baseline survey: n= 42. Personalized session: n= 32. Six-months follow-up: n= 37.	Pre-post study	Robot assisted surgery	Robotic surgeons were offered a slideshow-based ergonomic session focused on optimal robotic console setup. In addition, they were offered an optional 5-minute personalized session. The sessions were conducted by two study personnel both experienced in robotic surgery and trained in ergonomics.	Self-reported outcome: Proportion of participants with a reduction in body part MSP (% NMQ). Pre- and post-survey assessments obtained six months apart using questionnaires.	Of the 19 surgeons who reported MSP in the pre-intervention survey underwent ergonomic training and 74% (n= 14) noted a decrease in strain after training.	15
Giagio	Baseline: n= 141. Six-months follow-up: n= 126.	Cluster randomized controlled trial	Combination	Surgeons were randomized into one of two groups: 1) The intervention group participated in a preventive program consisting of two components: group or individual lectures about ergonomic principles, and the practice of dynamic and static exercises pre- and post-surgery,	Self-reported outcome: Body part MSP (0-10 NRS, NMQ) and proportion (%). Pre- and 6-month post-intervention assessments using questionnaires.	A significant improvement in the proportion of participants with MSP in the lower back was observed in the intervention group compared with the control group (72% vs. 53%), with trends noted for the upper back, neck, and shoulder, but no statistically significant between-group differences were found for any body region other than the lower back. No significant difference in MSP intensity between	23

delivered, and occasionally supervised, by a physical therapist.

groups, however, a trend was noted.

2) The control group did not receive any preventive program.

Hess	n= 6	Pre-post study	Combination	Laparoscopic surgeons participated in a holistic ergonomic program (CORE) with multimodal educational delivery methods over a 14 week period. It included informational handouts, ergonomics educational presentations and lectures, weekly live in-person or virtual coaching with an occupational therapist, strength and flexibility exercises, mindfulness, and lifestyle modifications.	Self-reported outcome: Body part MSP (0-10 Likert scale). Observer-based outcome: The Rapid Upper Limb Assessment (RULA). Assessed pre- and 14-week post Core-program. Assessed pre-, intra-, and post-operatively.	A significant improvement (decrease) in RULA scores was observed from pre- to post CORE-program. No significant change in body part MSP.	16
Yadav	Baseline survey: n= 71. Webinar participants: n= 46. Immediately post-webinar survey: n= 46. Two-months follow-up: n= 34.	Pre-post study	Unknown	Surgical residents were offered two, 1-h webinar educational sessions on surgical ergonomics, including contributing and exacerbating factors for MSK injuries and their consequences, the impact of extreme postures and positioning,	Self-reported outcome: MSP proportion (%). Assessed immediately post-webinar, and again two months post-webinar.	Two months post-webinar, 76% (n= 26) of residents stated that implementing the ergonomic recommendations had decreased their MSP symptoms.	15

injuries in
surgeons, and
equipment and
exercises.
The sessions
were delivered
one week apart
by experts in
the area of
surgical
ergonomics.

Median D&B score

15.5

Microbreaks

Study characteristics and methodological quality

Table 3 summarizes findings from four case-crossover studies in which participants act as their own controls [10, 15, 47, 48]. These studies evaluated the association of intra-operative microbreaks of 10 sec. to 5 min. duration, with or without stretching exercises, every 10 min. to 40 min, on various outcomes.

The median D&B score across these studies was 19 (range 14-20), indicating overall fair methodological quality. This rating reflects that all studies used case-crossover designs in which participants acted as his/her own control. In addition, the sample sizes were generally small and the number of intervention/control cases per surgeon was limited in two of the studies [15, 48], whereas two other studies had each surgeon perform several cases per condition [10, 47].

However, only two studies explicitly stated whether efforts were made to blind outcome assessors or those interpreting the results [15, 48].

Randomization methods were reported in three studies [15, 47, 48], although randomization was used only to determine the order of intervention and control conditions as part of a cross-over, within-subject design. All four studies report matching cases on intervention and control conditions.

Outcomes

One study assessed 16 surgeons under three conditions, in a total of 48 cases: 1) before and after a surgeon-selected surgical procedure, 2) before and after a surgical procedure of minimum two hours duration with 20 sec. microbreaks every 20 min., and 3) before and after a matched control surgical procedure without microbreaks. [15]. Another study assessed 12 surgeons before and after two surgical procedures in a total of 24 cases: one with 10 sec. microbreaks every 10 min., and one without microbreaks, totaling 24 cases [48]. A third study had seven surgeons perform multiple surgical procedures under two conditions in a total of 51 cases: with or without 5 min. microbreaks every 25 min., totaling 51 cases [47]. The largest study (7) assessed 56 surgeons and OR team members, in a total of 341 cases, before and after a full day of surgical procedures without

microbreaks, or a full day of surgical procedures with 90-120 sec. microbreaks every 20-40 min. with guided stretching exercises of the upper extremity and trunk [10].

Three of the studies [10, 15, 47] reported a significant reduction in MSP with microbreaks lasting from 20 sec. every 20 min. to 5 min. every 25 min., regardless of whether stretching exercises were included. In contrast, the study with 10 sec. microbreaks every 10 min. during a single operation found no significant effects on MSP, endurance, or exhaustion [48].

Table 3 Microbreaks

Author	No. of participants	Study design	Modality	Intervention details	Outcome type and measurement (tool)	Results	D&B score
Dorion	n= 16	Case-crossover	Combination	In 48 cases, each surgeon was assigned to three different conditions: 1) Intervention: A common and reproducible surgery lasting at least 2 hours with 20 sec. microbreaks every 20 min., during which surgeons were instructed to stop operating, step away from the workstation, and stretch their neck and shoulders (16 cases). 2) Control: A matched operation without microbreaks (16 cases). 3) Control: Any surgery (16 cases).	Self-reported outcome: Body part musculoskeletal pain (MSP) (100 mm VAS). Objective outcome: Muscular fatigue (straight-arm test holding 2.5 kg dumbbell). Outcomes were assessed pre- and post-operatively in a local site adjacent to the operating room.	Significantly lower MSP levels in the upper extremity, including the neck, back, shoulders, wrists and elbows, and prevention of muscular fatigue with microbreaks compared to control- and without-microbreak surgeries. No significant differences were observed for the legs and eyes.	14
Engelmann	n= 7	Case-crossover	LAP	In 51 cases, seven surgeons were randomized to one of two conditions: 1) Intervention: 5-minute unstructured breaks every 25 minutes during complex laparoscopic operations (26 cases). 2) Control: Complex laparoscopic operations without breaks (25 cases).	Self-reported outcomes: MSP (1-10 NRS). Fatigue and perceived intraoperative impairment by fatigue (NASA-TLX (0-10)). Outcomes were assessed post-operatively using questionnaires.	Significantly lower MSP for the upper extremity, including the neck, shoulders, elbows, wrists, hands, and fingers, upper and lower back, and prevention of fatigue and perceived intraoperative impairment by fatigue, in the cases with breaks, compared to cases without breaks.	19

Hallbeck	n= 56 (incl. OR team)	Case- crossover	Combination	In a total of 341 cases, two conditions were tested on two separate days, scheduled one week apart: 1) Intervention day: 90-120 sec. guided intraoperative microbreaks with dynamic stretching exercises at 20-40 min. intervals throughout each case over a surgical day (148 cases). 2) Control day: Matched cases without microbreaks and stretches (193 cases). A study team member led the surgeon through the standardized microbreak stretching exercises.	Self-reported outcome: Body part MSP (0-10 NRS, NMQ). Outcomes were assessed preliminarily, at the beginning of each study day, pre- and post-operatively, and at the end of the day using questionnaires.	Significant improvement in MSP in the right and left shoulders (and trends toward improvement for the hands) on the days with microbreaks with stretching exercises compared to the operative days without. No significant differences were observed for the neck, hands, lower and upper back, knees, or feet.	19
Kromberg	n= 12	Case- crossover	LAP	The order of 24 cases was randomized to one of two conditions: 1) Intervention: 10-second intraoperative microbreaks, featuring stretching exercises every 10 minutes, guided by an investigator (12 cases). 2) Control: Matched cases without microbreaks (12 cases).	Self-reported outcome: Body part MSP (100 mm VAS). Level of exhaustion (BorgCR10 scale). Objective outcome: Muscular fatigue (straight-arm test holding 2.5 kg dumbbell). Outcomes were assessed three times: once before a surgery, once after a no-intervention surgery, and once after an intervention surgery.	No significant difference in MSP, level of exhaustion, or muscular fatigue between control condition and surgery with microbreaks.	20

Median D&B score **19**

OR Posture Optimization

Study characteristics and methodological quality

Table 4 summarizes six studies: five case-crossover studies and one pre-post study that investigated the impact of posture optimization in the OR [41, 49-53]. Participant numbers ranged from three to 32. The median D&B score across these studies was 16.5 (range 15-19), indicating overall fair methodological quality. Most studies used a case-crossover design, where the same participants were assessed in both the intervention and the control conditions, apart from one pre-post study unclear follow-up procedures. Overall, sample sizes were small with a limited number of intervention/control cases per surgeon.

Randomization methods were reported in one study [7], although randomization was used to determine the order of intervention and control conditions. Four studies report matching cases in control and intervention conditions [41, 49-51].

Outcomes

Three studies, published between 2002 and 2010, focused on ergonomic monitor positioning [49-51], used a similar case-cross over design in which the surgeons acted as their own controls.

In these studies, each surgeon performed a total of two laparoscopic surgical procedures - one in an ergonomically optimized OR with multiplanar adjustable flat-screen monitors, and one in a standard OR with a conventional monitor tower with limited adjustment options. These studies reported 16, 20, and 24 cases, respectively [49-51].

In a more recent study from 2022, each surgeon performed a total of six surgical procedures – in three surgical procedures the surgeons wore augmented reality glasses (ARG) as visual aid that allowed the surgeon to view the monitor and surgical site simultaneously without neck or torso movements. These cases were compared to three surgical procedures using conventional monitors [52]. Compared to the standard OR setup, the ergonomically optimized modern ORs with better monitor adjustment options, led to reduced MSP in the right neck and shoulder, and reduced MSP in the right lower arm [49]. Additional improvements included reduced overall MSP, and improved neck posture for both assisting and primary surgeons [50, 51], although one study reported improvements in neck posture for the assisting surgeon but not the primary surgeon, and vice versa in another. The more recent study that evaluated a newer technology found that ARG worn by the surgeon, as opposed to using conventional monitors, reduced muscular fatigue during surgical procedures and improved overall working posture, especially in the neck and shoulder regions [52].

A pre-post pilot-study focused on improving robotic surgeons' posture. In a total of 36 cases, six robotic surgeons completed three surgical procedures in each of the two conditions: 1) using their own console settings and 2) optimized ergonomic positioning of the console.

While no substantial improvements in MSP were reported, ergonomist-specified robot console settings led to significant postural improvements in the neck, trunk and left arm, and decreased time spent in moderate- to high-risk postures, compared to the surgeons' own console settings [41].

Another study involving surgical residents comprised two phases; identification (Phase 1) and evaluation (Phase 2) of multiple intraoperative ergonomic strategies, including separate monitors for the surgeon and assistant, allowing assistant to sit on adjustable chair, feedback on table height/position, monitor angle/position and on positional changes, as well as 5 min. breaks every 1–2 h of surgery [53]. This study reported no significant change in the proportion of participants reporting physical symptoms or severe MSP. However, participants rated separate monitors for the primary surgeon and assistants, and intraoperative feedback on monitor angle or position, as the most useful. The findings were based on 46 pre- and 64 post-intervention questionnaire responses provided by a total of 32 participants. As the number of unique respondents per phase was not reported, it is unclear whether pre- and post-intervention responses were paired.

Table 4 OR Posture Optimization

Author	No. of participants	Study design	Modality	Intervention details	Outcome type and measurement (tool)	Results	D&B score
Chan	Residents: n= 32. Baseline survey: n= 46. 4-months follow-up: n= 64.	Pre-post study	Combination	In phase 2, surgical residents were introduced to intraoperative measures to improve ergonomics. These included: A. Separate monitors for surgeon and assistant B. Allowing assistant to sit on adjustable chair C. Feedback on table height/position D. Feedback on monitor angle/position E. Feedback on positional changes	Self-reported outcome: Physical symptoms (1-5 NRS). Body part MSP (1-5 NRS). Assessed pre-and 4-months post application of ergonomic measures, using questionnaires.	No significant change in the proportion reporting physical symptoms or severe MSP. Comparability between Phase 1 and Phase 2 participants remains uncertain.	15

				F. 5-min break every 1–2 h of surgery			
Hokenstad	n= 6	Case-crossover study	Robot assisted surgery	In a total of 36 cases, robotic surgeons performed three matched surgeries under two conditions: 1) Intervention: Participants used an ergonomist-derived configuration of the robotic console. 2) Control: Participants used their usual settings on the robotic console (da Vinci Xi surgical system).	Self-reported outcome: Body part MSP (1-4 Likert scale, Cornell Musculoskeletal Discomfort Questionnaire). Assessed immediately pre- and post-surgery. Objective outcome: Postural strain (time and body angles (inertial measurement unit (IMU) sensors, and modified rapid upper limb assessment (RULA)). Recorded during operations.	No significant change in MSP. The neck angle decreased significantly (indicating improvement) when the ergonomist-specified settings were used. The other joint angles (trunk and arms decreased, but not significantly). The time in which the neck and right arm spent in moderate to high-risk categories decreased when using the ergonomist-specified console settings. A decrease was observed in the trunk and left arm, but it was not significant.	19
Klein	n= 10	Case-crossover	LAP	In a total of 20 matched cases, each surgeon performed a surgery under two different conditions: 1) Intervention: Modern OR equipped with two movable flat-panel monitors mounted on the ceiling. 2) Control: Standard OR with the monitor	Self-reported outcome: Body part MSP (100 mm VAS). Physical strain (Borg CR-10). Outcomes were assessed pre- and post-operatively using questionnaires.	Significant reduction in MSP in the right lower arm, and physical strain in the right neck and shoulder in the modern OR compared to the standard OR. No significant differences were observed for MSP in the left lower arm, and physical strain in the left neck and shoulder.	18

positioned on top of a laparoscopy rack.

Lim	n= 3	Case-crossover	Combination	In a total of 18 cases, each surgeon performed six surgeries, divided between two different conditions: 1) Intervention: Using augmented reality glasses Augmented Reality Glasses (ARG). 2) Control: Using conventional Monitors.	Objective outcome: Muscular fatigue (EMG). Subjective physical workload (NASA-TLX). Observer-based outcome: Risk of musculoskeletal disorders (REBA). Outcomes were assessed during or post-operatively.	Significant reduction in signs of muscular fatigue in the neck and shoulders, and significantly lower REBA scores with ARG compared to conventional monitors. No significant difference in fatigue was observed for the back and lower arms. Maintenance or improved overall subjective workload with ARG, however, physical workload was not reported separately.	15
van Det	n= 32	Case-crossover	LAP	The order of 16 matched cases was randomly assigned to one of two operating room (OR) setups: 1) Intervention: A Minimally Invasive Surgery (MIS) Suite with three adjustable flat-screen monitors suspended from the ceiling. 2) Control: A traditional OR setup with a single monitor placed on top of a laparoscopic trolley.	Self-reported outcome: Subjective physical workload (NASA-TLX).MSP (0-100 mm VAS). Ergonomic quality of posture (0-100 mm VAS). Both recorded post-operatively. Objective outcome: Neck posture (video analysis system). Recorded during operations.	All surgeons experienced significantly less MSP, and rated the quality of their ergonomic posture significantly higher in the MIS suite, compared to the traditional OR. All surgeons significantly reduced neck rotation, but neck flexion improved for the primary surgeon only, not the assisting surgeon.	17

Veelen	n= 12	Case- crossover	LAP	In a total of 24 matched cases, each surgeon participated in two OR setups: 1) Intervention: A flat-screen monitor positioned ergonomically. 2) Control: A CRT Monitor mounted on a tower next to the operating table, reflecting the current standard setup.	Self-reported outcome MSP (0-100 mm VAS). Recorded post-operatively. Objective outcome: Neck posture (ProReflex 3D tracking system). Recorded during operations.	Significant reduction in MSP for all surgeons. Improved neck posture (flexion and rotation) for the assistant surgeon only, and not the operator, when using the flat-screen monitor setup compared to the using the CRT monitor setup.	16
Median D&B score							16.5

Body Support Devices

Study characteristics and methodological quality

Table 5 summarizes four case-crossover studies investigating the use of body support devices to reduce postural strain, with variations in design, outcomes and assessment tools.

The median D&B score was 15.5 (range 14-17), indicating fair methodological quality. A case-crossover design was used in all studies, and the number of cases per surgeon in each condition was limited, and sample sizes were small, partly because two studies were pilot-studies [37, 39].

Randomization methods were reported in two studies [39, 42], although it was used to determine the order of intervention and control conditions as part of a cross-over, within-subject design. Two studies reported matching cases to control and intervention conditions [42, 54].

Outcomes

Upper body support devices

Two pilot-studies focused on upper body support using a passive arm exoskeleton support [39, 42]. In one of those studies, seven surgeons wore an arm exoskeleton during one operative day and were compared to themselves on a matched operative day without wearing the exoskeleton [42]. In the other study, seven surgeons wore an arm exoskeleton in a total of 27 cases, 12 cases with the device and 15 cases without [39].

With the arm exoskeleton, surgeons reported significantly less shoulder MSP, but not in other body regions, and six out of the seven reported less MSP at the end of the day with the exosuit [42]. On the contrary, the other study [39] reported no MSP reduction, but reported a significant reduction in the duration of holding the right shoulder in a high risk posture, but not in other body angles. Further,

wearing the exoskeleton decreased peak muscle activation in the right deltoid, decreased peak and median muscle activation of the left trapezius and right lumbar erector spinae muscles; and decreased fatigue and static muscle activation in the left trapezius, while no significant decreases were observed in the left deltoid, right trapezius, or left lumbar erector spinae [39].

Overall, the findings suggest possible ergonomic benefits of upper body support devices, particularly for posture and EMG-assessed muscle load, whereas effects on MSP were less consistent.

Lower body support devices

Two studies evaluated lower body support devices designed to reduce muscle activity in standing. One study assessed a wearable support device that helps the surgeon maintain a near-standing posture by supporting the lower limbs, while the other evaluated a free-standing surgical knee rest designed to reduce lower limb strain [37, 54]. In both, surgeons acted as their own controls and performed a surgical procedure with the lower limb support device, and one operation without it, totaling 6 and 10 cases, respectively.

One of the studies (a pilot-study) found no statistically significant reduction in iliopsoas muscles activity, although a trend was noted on the left side when using a lower limb support device [37]. In contrast, the second study demonstrated significantly reduced activity in both left and right gastrocnemius muscles during the initial 50 min. of surgery with the device; however, over the full 100 min. period, only the left gastrocnemius showed a sustained significant reduction [54]. These two studies cautiously suggest that lower body support devices may reduce lower extremity muscle activity in standing, although the evidence was limited and not consistent across muscles.

Table 5 Body Support Devices

Author	No. of participants	Study design	Modality	Intervention details	Outcome type and measurement (tool)	Results	D&B score
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Cha	n= 7 (incl. 1 surgical nurse)	Case-crossover	Combination	In a total of 27 cases, participants performed surgery in two conditions, the order randomized: 1) Intervention: Wearing an arm-support exoskeleton (Levitate AIRFRAME™) during surgery (12 cases). 2) Control condition: Performing surgery without the arm exoskeleton (15 cases).	Self-reported outcome: Body part musculoskeletal pain (MSP), overall physical discomfort and perceived effort in upper-body (0-10 NRS). Recorded pre- and post-operatively. Objective outcome: Body posture (time, inertial measurement units (IMU) motion tracking). Muscle activity (EMG). Both recorded during operations.	No significant difference in any body part MSP or perceived upper-body effort, from pre-to post surgery between cases with and without the device. Significantly reduced time in demanding postures for the right shoulder, but not for the left shoulder, neck and trunk. Significantly decreased peak and median muscle activation (50 and 90th%ile) in the right deltoid, left trapezius, and right erector spinae; and fatigue (10th%ile) reduced in the left trapezius only. No significant difference in any muscle activation metrics of the left deltoid, right trapezius, and left lumbar erector spinae.	17
Kawahira	n= 3	Case-crossover	LAP	In a total of six cases, each surgeon performed two surgeries in each of the following conditions: 1) Intervention: Wearing the Lower Limb Support Device (Archelis) during the surgery. 2) Control: No Lower Limb Support Device.	Self-reported outcome: Tiredness (7-point Likert scale). Recorded post-operatively. Objective outcome: Iliopsoas muscle activity (EMG). Recorded during operations.	No significant reduction in iliopsoas muscle activity. A decrease trend was observed in the left iliopsoas muscle. Tiredness data were not reported by the authors	14

Liu	Phase 3: n= 7	Case-crossover	LAP	Over two matched operative days, each surgeon was randomized to the following conditions on the first or second day: 1) Intervention: Wearing an arm exoskeleton (Levitare). 2) Control: No exoskeleton.	Self-reported outcome: Body part MSP (NMQ). Recorded at the beginning and at the end of the day.	Exoskeleton use was associated with a significant reduction in shoulder MSP. Reductions were observed in the neck, upper arm, wrist, and knee, but differences were not statistically significant. Composite MSP scores from all body regions showed a 70% reduction in MSP, although this was noted as a trend. Six out of the seven (86%) reported less MSP at the end of the operating day with the exosuit compared to without it.	15
Nishimoto	n= 5	Case-crossover	LAP	In a total of 10 matched surgeries, each surgeon participated in two surgeries under the following conditions: 1) Intervention: Using a surgical knee rest during the operation. 2) Control: No use of a surgical knee rest.	Objective outcome: Gastrocnemius muscle activity (EMG). Recorded during the first 100 min. of surgery.	Significant reduction in the left gastrocnemius muscle activity with the knee rest device compared to without. No significant reduction was observed in the right gastrocnemius muscle for the full 100 min.	16
Median D&B score							15.5

Miscellaneous Ergonomic Devices

Study characteristics and methodological quality

Table 6 presents findings from five observational studies evaluating the impact of three types of ergonomic devices [36, 38, 55-57]. The studies varied widely in design, sample size, interventions and outcomes.

The median D&B score was 18 (range 8-21) indicating fair methodological quality. All but one study used a case-cross over design, using the same individual for the intervention and control condition, generally in a limited number of cases. Overall, samples sizes were small, partly because of two pilot studies. Two studies randomized the order of the intervention and control condition [38, 55], and two

studies matched the surgical cases.

Randomization methods were reported in four of the studies [36, 38, 57, 59], although randomization was used to randomize the procedures (Haramis), or to determine the order of intervention and control conditions as part of a cross-over, within-subject design. Two studies mention matching cases in intervention and control conditions [36, 57].

Outcomes

Surgical seats

Two studies evaluated surgical seating [38, 56]. In one case-crossover pilot study that included pre–post intervention assessments as well as intraoperative observations of posture and muscle activation, six surgeons each performed one procedure using an ergonomic chair and another using a standard office chair [38]. Outcomes assessed included MSP, posture, muscle activity, and perceived physical exertion. No significant differences were observed in any of the measured outcomes.

The second study compared conventional and robot-assisted laparoscopy to an OR platform (“Ethos”), which supports the surgeon in a seated position during laparoscopic operations [56]. One surgeon performed 53 cases under each of the three conditions. The platform was associated with lower MSP levels than conventional laparoscopy, but higher MSP than robotic-assisted laparoscopy.

Anti-fatigue floor mats

Two case-crossover studies investigated the effect of anti-fatigue floor mats on MSP and fatigue by comparing surgical procedures performed with and without mats, in a total of 176 cases [55, 57]. With the anti-fatigue mats, participants reported significantly reduced overall MSP and in selected body regions and fatigue immediately post-operatively [55, 57], with effects persisting in the feet only up to 24 hours post-operatively in one study [55]. Furthermore, in one study, cases without the mats were associated with more perceived surgical errors because of discomfort and fatigue [55].

A rotatable laparoscopic handle

A pilot-study investigated the use of a rotatable laparoscopic handle versus a fixed handle, in a total of 40 cases [36]. Although no reduction in upper-body muscular fatigue or stress was observed, the participants reported improved wrist posture and comfort when using the rotatable handle in 75% of the cases.

Table 6 Miscellaneous Ergonomic Devices

Author	No. of participants	Study design	Modality	Intervention details	Outcome type and measurement (tool)	Results	D&B score

Dalager	n= 6	Case- crossover	Robot assisted surgery	In a total of 12 cases, each surgeon performed two surgeries in a randomized order, both conducted sequentially on the same day, the conditions being: 1) Exposure: Seated on one of two ergonomic chairs (determined by the surgeon preference). 2) Control: Seated on a regular office chair.	Self-reported outcome: Body part MSP (0-10 NRS, NMQ). Recorded pre-operatively using questionnaires. Perceived physical exertion (Borg CR-10 scale). Recorded pre- during and post-operatively using verbal feedback. Objective outcome: Muscle activity (5% threshold of %MVE for high static muscle activity). Recorded intraoperatively using EMG. Observer-based outcome: Postural observation (RULA). Recorded intraoperatively by observation.	No differences in any outcome measurements between the two chairs that could be considered clinically relevant.	19
Haramis	n= 18 (incl. OR team)	Case- crossover	Combination	In a total of 100 cases, the surgical teams were randomized to two different conditions: 1) Exposure: Using a foot gel mat during operations (n= 50 cases). 2) Control: No foot gel mat (n= 50 cases).	Self-reported outcome: Body part MSP (1-10 NRS). Recorded pre-, immediately post-, and 24h post-operatively using a questionnaire. Fatigue. Assessed as a yes/no question about feeling "more or less fatigued".	Significantly lower MSP in the feet, knees, back, overall MSP, and fatigue immediately after surgeries with the gel mat compared to without. No significant difference was observed for the ankles, hips, shoulders and neck. Significantly lower MSP in the feet and overall discomfort 24-hours post-operatively. No significant difference from was observed for the ankles, knees, hips, back, shoulders and neck.	18

Kraemer	n= 11	Case- crossover	LAP	Over two study days, a total of 40 matched cases were randomly assigned to one of two conditions: 1) Exposure: Pistol grip standard laparoscopic instrument with a 360° rotatable handle piece (rotating ERGO handle 20195-240, ERBE Elektromedizin GmbH, Germany) (20 cases). 2) Control: Pistol grip standard laparoscopic instrument with a fixed handle piece (handle 20195-145, ERBE Elektromedizin GmbH, Germany) (20 cases).	Self-reported outcome: One item-question about wrist posture (7-level Likert scale), assessed post-operatively. Objective outcome: Shoulder and arm muscular stress and fatigue (EMG), measured intraoperatively.	No significant differences in muscular stress and fatigue between the two instruments, but wrist posture was more comfortable using the rotatable handle piece.	18
Rassweiler	n= 1	Comparative study	LAP	In a total of 159 cases, a single surgeon compared three different surgical approaches: 1) Exposure: The Ethos chair (53 cases). 2) Comparison: Conventional Laparoscopic Surgery standard laparoscopic techniques (53 cases). 3) Comparison: Robot-Assisted Laparoscopic Surgery with the da Vinci S system (53 cases).	Self-reported outcome: Body part MSP (NRS 0-5). Recorded pre- and postoperatively.	The reporting of the outcome is unclear, but the surgeon reported lower overall MSP when using the Ethos chair compared to conventional laparoscopy, but higher MSP compared to the robotic approach.	8

Unver	n= 38 (incl. OR team)	Case- crossover	Combination	In a total of matched 76 cases, participants completed one surgery under each of two experimental conditions: 1) Exposure: Standing on the anti-fatigue floor mat (Artlines, Ateco Ground Materials, Istanbul, Türkiye) during the surgery (with-mat condition). 2) Control: Standing on the standard floor during the surgery (no-mat condition). Participants were asked to wear the same foot wear during both experimental conditions.	Self-reported outcome: Any body part MSP (0-10 NRS). Recorded pre- and post-operatively. Fatigue severity (0-10 NRS). Recorded pre- and post-operatively.	Significantly lower post-surgery MSP and fatigue scores with the mat compared to without.	21
Median D&B score							18

Methodological quality and limitations

The methodological quality was assessed using the Downs and Black (D&B) checklist. Based on this assessment, no studies were rated as "excellent" (score 26–28), while methodological quality was rated as "good" (score 20–25) in three studies [44, 48, 57], "fair" (score 15–19) in 18 studies [10, 36, 38-43, 45-47, 49-54, 59], and "poor" (score ≤ 14) in 4 studies [15, 35, 37, 56]. The methodological quality of the studies varied across the different types of interventions or exposures. The methodological issues are summarized below.

Reporting and generalizability

Selection and recruitment procedures were often inadequately described, apart from a few studies [10, 38, 44]. In general, the representativeness of the study samples was rarely addressed. Ten studies did not report comprehensive participant characteristics [15, 35, 42, 47, 48, 50-52, 60], which may reflect concerns about identifiability in pilot-studies and other small-sample studies and limit generalizability.

Bias (internal validity)

Blinding of participants was generally not feasible due to the nature and short duration of the interventions.

Confounding

Several studies tried to control for potential confounders by matching case characteristics (e.g., time of day, case type or complexity [10, 15, 36, 41, 42, 47-51, 54, 57]) or using case-crossover designs, where participants served as their own controls. A list of relevant confounders specific to surgical ergonomics studies can be found in Table 8 (Suppl. materials).

Power

Three studies [44, 48, 50] reported conducting sample size or power calculations. The lack of statistical power consideration in most studies, along with generally small sample sizes, may have limited the ability to detect meaningful differences or effects. That being said, 10 studies are either pilot [35-41] or feasibility studies [42, 43] with objectives other than assessing the effect of an ergonomic intervention/exposure.

DISCUSSION

Summary of findings

This systematic review synthesized existing evidence on the association between ergonomic interventions in the OR on musculoskeletal health and workload outcomes among abdominal and pelvic surgeons. Twenty-five studies were included, predominantly observational in design, employing self-reported, observer-based and objective outcome measurements, with substantial heterogeneity and overall fair methodological quality. Collectively, they represent an early but meaningful evidence base for ergonomic interventions in live OR settings. Across intervention types, the most consistent findings were associations between microbreaks, OR posture optimization, and ergonomic education and reductions in self-reported MSP and improvements in biomechanical/posture outcomes, whereas effects on objective measures of muscular workload were less consistent. The findings are summarized below by outcome category: proportion of participants reporting a pain reduction, absolute pain reduction, musculoskeletal workload (fatigue), and biomechanical assessments.

Effects by outcome category

Proportion of participants reporting a pain reduction

Ergonomic education demonstrated the most consistent association with reductions in the proportion of participants reporting MSP. These interventions typically incorporated extended follow-up periods, potentially facilitating behavioral change and integration of ergonomic practices into routine surgical activities. However, the educational content frequently incorporated multiple components, including instructions on OR posture optimization and microbreak protocols, complicating the isolation of individual associations. This overlap between intervention categories is a limitation of the categorization approach used in this review and should be considered when interpreting findings. Nevertheless, these results align with existing reviews [61, 62].

While extended follow-up periods represent a methodological strength, several limitations compromise interpretation. These include pilot and feasibility study designs with limited statistical power, substantial loss to follow-up, potential selection bias, and considerable heterogeneity in both intervention content and outcome assessment methods. Critically, the degree of participant adherence to ergonomic principles remains unknown, and the influence of confounding factors cannot be adequately assessed.

Absolute pain reduction

Microbreaks and OR posture optimization were the interventions most frequently associated with reductions in reported MSP intensity. Microbreaks of 2-5 min. duration, implemented at regular intervals during surgical procedures exceeding two hours, were associated with significant reductions in pain and muscular fatigue across three studies. Conversely, one study examining microbreaks in shorter surgical durations found no significant benefit, suggesting a duration-dependent relationship. Despite this, evidence from studies conducted in other occupational settings, as well as findings from systematic reviews, consistently supports the positive impact of microbreaks on MSP [63-65]. This differential effectiveness aligns with established muscle physiology principles. During prolonged static muscle contractions characteristic of surgical positioning, intramuscular pressure increases, compromising local blood flow and oxygen delivery while promoting metabolite accumulation. These physiological changes typically manifest after prolonged periods of sustained low-level muscle activity [66], explaining why shorter procedures may not benefit from microbreak protocols. For surgeries lasting less than two hours, strategically implementing microbreaks between consecutive surgical procedures may be worth considering. Future research should systematically evaluate microbreak protocols across varying surgical durations using standardized methodologies. The present evidence is characterized by considerable heterogeneity in sample sizes, selection

strategies, intervention durations, and the definitions and measurements of outcomes. Factors such as the use of pain-relief medication, psychological stress, physical activity levels, and workload indicators (e.g., caseload and weekly working hours) should be systematically recorded and reported to ensure more accurate interpretation of intervention effects. Collectively, these methodological inconsistencies limit both internal and external validity of existing findings.

Among the interventions targeting posture optimization during laparoscopic procedures, the most consistent reductions in MSP were observed in studies comparing modern operating rooms (ORs) to conventional ORs, with results favoring the modern OR settings and adjustment options. Notably, the three studies that reported significant reductions in MSP all involved laparoscopic surgery [49-51]. In contrast, the three studies that did not find significant reductions in MSP employed a mix of surgical modalities [41, 52]. This discrepancy may be attributed to the higher physical demands of laparoscopy, which is known to place greater strain on posture and is associated with increased rates of upper extremity complaints compared to other surgical techniques [26, 38].

The physiological lag between improved OR posture and MSP relief may extend beyond the typical study observation periods employed in current studies. Evidence from the broader literature indicates that noticeable reductions in MSP often manifest after approximately seven weeks of intervention [67]. Further, the short intervention durations, typically involving a single surgical procedure under both control and experimental conditions, and unclear selection criteria, are limitations to internal and external validity. Future studies should incorporate larger sample sizes and extended follow-up periods to better capture the temporal relationship between postural improvements and MSP reduction.

Musculoskeletal Workload (fatigue)

Microbreaks and OR posture optimization were associated with reductions in musculoskeletal workload. Regular microbreaks and postural adjustments interrupt prolonged periods of static loading, facilitating recovery from metabolic disturbances associated with muscle fatigue [68]. From a physiological perspective, brief activity interruptions enhance local circulation and promote metabolite clearance, thereby attenuating the progression toward muscular exhaustion. Limited evidence from two studies suggests potential benefits of body support devices for reducing fatigue in both upper and lower extremities. However, these findings remain inconsistent, and the evidence base is insufficient for definitive recommendations.

Biomechanical assessments

While the effects of OR posture optimization on MSP intensity were variable, improvements in biomechanical parameters such as Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and joint angle analysis were consistently observed. Ergonomically optimized OR environments reduce mechanical loading on musculoskeletal structures by promoting joint alignment within neutral ranges and minimizing moment arms, thereby lowering muscular strain and delaying the onset of fatigue. A notable methodological strength across these studies was the assessments of outcomes during actual surgical procedures, coupled with the use of objective or observer-based posture evaluations. Although reductions in postural strain are theoretically linked to decreased mechanical stress, the relatively short duration of most interventions may have limited the ability to detect corresponding reductions in subjective outcomes such as MSP, especially long-term or sustained.

Future studies should incorporate larger sample sizes, longer intervention periods, and blinded observer assessments to enhance both the internal and external validity of findings.

Methodological quality and limitations

All studies were included regardless of bias of risk, allowing for broader synthesis of the available evidence. However, this approach also introduces greater uncertainty due to the variable methodological quality across studies, including the inclusion of pilot and feasibility studies. The short duration of the interventions, especially in case crossover studies, may have limited the ability to observe their full effects.

Moreover, few studies reported power calculations, which may increase the risk of bias, may lead to potentially biased interpretations, and limits generalizability of findings. Randomization was rarely surgeon-specific, and blinding was uncommon. Key confounding factors such as complexity of cases were frequently accounted for, however pre-existing pain intensity, intake of pain medication, and physical activity level were rarely reported, limiting the validity of findings. We used the Downs and Black checklist to assess bias across randomized and non-randomized studies for consistency, though a tool specific to each observational study design might have better captured study quality.

Implications and Future Directions

Implications for surgical practice

The present review identified three intervention types *with* consistent trends pointing toward potential benefits. *These were* microbreaks, OR posture optimization, and ergonomic education, *and these intervention types* share a common characteristic: they are low-cost, require no specialized equipment, and can be integrated into existing surgical workflows without major changes to existing

surgical workflows or infrastructure.

Regular microbreaks of 2-5 min. during surgical procedures were associated with reductions in MSP and fatigue in procedures exceeding two hours. Additionally, OR posture optimization was consistently associated with improvements in biomechanical parameters and warrants prioritization in future research, even though its immediate impact on pain relief may vary. Ergonomic education programs were associated with reductions in the proportion of surgeons reporting MSP, particularly when implemented with extended follow-up periods.

Implications for research

Future research must address critical methodological limitations through more rigorous approaches. Adequately powered studies with standardized outcome measurements, extended follow-up periods and comprehensive outcome assessments that include both objective and subjective measurements are essential. While RCTs represent the gold standard, they may not always be feasible in an OR environment due to practical and ethical constraints. Thus, researchers conducting observational studies are encouraged to systematically measure and report known confounding variables relevant to surgical ergonomics. Doing so enables more accurate interpretation of whether observed effects are likely attributable to the intervention itself or influenced by other factors.

Surgical ergonomics training is increasingly being incorporated into curricula for robotic surgeons and residents, demonstrating feasibility and relevance [43, 69, 70]. However, despite the availability of surgical ergonomic guidelines [71, 72], awareness and adoption among surgeons remains limited [19, 24]. Future research should prioritize developing effective dissemination strategies and exploring barriers to adoption. Successful implementation requires coordinated efforts across individual, peer, and institutional levels, with particular emphasis on securing commitment and allocating necessary resources for sustainable program delivery [73].

CONCLUSION

Ergonomic interventions in the OR are associated with reductions in musculoskeletal pain and improvements in working posture among abdominal and pelvic surgeons. The most consistent trends were observed for microbreaks, OR posture optimization, and ergonomic education. These interventions are low-cost and can be integrated into existing surgical workflows without significant organizational change. The evidence base remains limited by observational designs, small samples, methodological heterogeneity, and short follow-up periods, and current findings should be regarded

as promising but preliminary. Rigorous, adequately powered trials with standardized outcome measures are needed to establish effectiveness and support evidence-based implementation.

SUBMITTED

ACKNOWLEDGEMENTS

Funding

This work was supported by The Working Environment Research Fund (grant number 20215100734) and Aarhus University. None of the funders are involved in any other aspect of the project, such as the design of the project's protocol and analysis plan, the collection and analyses. The funder provides no input on the interpretation or publication of the study results.

Acknowledgement

We acknowledge with sadness that our co-author, Pernille Tina Jensen, passed away during the review process. We are grateful for her valuable contribution to this work.

Summary Declaration Of Competing Interests

The authors report no competing interests.

Author Contribution

HJC contributed to conceptualization, methodology, formal analysis, investigation, writing of the original draft, and project administration. HN, ET, SH, KC, OM, PTJ and TD contributed to conceptualization, methodology, investigation, critical review of the manuscript for important intellectual content, and TD contributed to and funding acquisition.

Declaration Of Generative AI And AI-Assisted Technologies In The Writing Process

During the preparation of this work, the author(s) used ChatGPT and Microsoft Copilot to support the writing process by improving the readability and language of the manuscript. After using this tool, the author(s) reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Data availability

The corresponding author can be contacted for reasonable requests to access supporting materials, including literature search strategies and data extraction forms.

REFERENCES

1. de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Luxembourg: European Agency for Safety and Health at Work; 2019.
2. Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of Work-Related Musculoskeletal Disorders Among Surgeons and Interventionalists: A Systematic Review and Meta-analysis. *JAMA surgery*. 2018;153(2):e174947-e.
3. Alleblas CCJ, de Man AM, van den Haak L, Vierhout ME, Jansen FW, Nieboer TE. Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive Surgery: A Systematic Review. *Ann Surg*. 2017;266(6):905-20.
4. Dalager T, Sogaard K, Boyle E, Jensen PT, Mogensen O. Surgery Is Physically Demanding and Associated With Multisite Musculoskeletal Pain: A Cross-Sectional Study. *J Surg Res*. 2019;240:30-9.
5. Adams SR, Hacker MR, McKinney JL, Elkadry EA, Rosenblatt PL. Musculoskeletal pain in gynecologic surgeons. *J Minim Invasive Gynecol*. 2013;20(5):656-60.
6. Stucky CH, Cromwell KD, Voss RK, Chiang YJ, Woodman K, Lee JE, et al. Surgeon symptoms, strain, and selections: Systematic review and meta-analysis of surgical ergonomics. *Ann Med Surg (Lond)*. 2018;27:1-8.
7. van Det MJ, Meijerink WJ, Hoff C, van Veelen MA, Pierie JP. Ergonomic assessment of neck posture in the minimally invasive surgery suite during laparoscopic cholecystectomy. *Surgical endoscopy*. 2008;22(11):2421-7.
8. Van Det MJ, Meijerink WJHJ, Hoff C, Totte ER, Pierie JPEN. Optimal ergonomics for laparoscopic surgery in minimally invasive surgery suites: A review and guidelines. *Surgical Endoscopy*. 2009;23(6):1279-85.
9. Dalager T, Jensen PT, Eriksen JR, Jakobsen HL, Mogensen O, Sogaard K. Surgeons' posture and muscle strain during laparoscopic and robotic surgery. *Br J Surg*. 2020;107(6):756-66.
10. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Appl Ergon*. 2017;60:334-41.
11. Fox M. Surgeons Face Unique Ergonomic Challenges [Internet]. Available from: <https://www.facs.org/for-medical-professionals/news-publications/news-and-articles/bulletin/2022/september-2022-volume-107-issue-9/surgeons-face-unique-ergonomic-challenges/>; American College of Surgeons; 2022 [
12. Chambers A, Gill N. Work related musculoskeletal pain in general surgical trainees: extent of the problem and strategies for injury prevention. *The Bulletin of the Royal College of Surgeons of England*. 2020;102(S1):e9-e14.
13. GlobalData Plc. The Complexities of Physician Supply and Demand: Projections From 2021 to 2036. Washington, DC: Association of American Medical Colleges,; 2024.
14. Davis WT, Fletcher SA, Guillaumondegui OD. Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. *J Surg Res*. 2014;189(2):207-12 e6.
15. Dorion D, Darveau S. Do micropauses prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. *Annals of surgery*. 2013;257(2):256-9.
16. Seagull FJ. Disparities between industrial and surgical ergonomics. *Work*. 2012;41 Suppl 1:4669-72.
17. Matern U. Ergonomic deficiencies in the operating room: examples from minimally invasive surgery. *Work*. 2009;33(2):165-8.

18. Wauben LS, van Veelen MA, Gossot D, Goossens RH. Application of ergonomic guidelines during minimally invasive surgery: a questionnaire survey of 284 surgeons. *Surg Endosc.* 2006;20(8):1268-74.
19. Catanzarite T, Tan-Kim J, Menefee SA. Ergonomics in gynecologic surgery. *Curr Opin Obstet Gynecol.* 2018;30(6):432-40.
20. Sari V, Nieboer TE, Vierhout ME, Stegeman DF, Kluivers KB. The operation room as a hostile environment for surgeons: physical complaints during and after laparoscopy. *Minim Invasive Ther Allied Technol.* 2010;19(2):105-9.
21. Liang B, Qi L, Yang J, Cao Z, Zu X, Liu L, et al. Ergonomic Status of Laparoscopic Urologic Surgery: Survey Results from 241 Urologic Surgeons in China. *PloS one.* 2013;8(7):e70423-e.
22. Cavanagh J, Brake M, Kearns D, Hong P. Work environment discomfort and injury: an ergonomic survey study of the American Society of Pediatric Otolaryngology members. *Am J Otolaryngol.* 2012;33(4):441-6.
23. Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg.* 2010;210(3):306-13.
24. Dalager T, Søgaard K, Bech KT, Mogensen O, Jensen PT. Musculoskeletal pain among surgeons performing minimally invasive surgery: a systematic review. *Surgical endoscopy.* 2017;31(2):516-26.
25. Armijo PR, Huang CK, High R, Leon M, Siu KC, Oleynikov D. Ergonomics of minimally invasive surgery: an analysis of muscle effort and fatigue in the operating room between laparoscopic and robotic surgery. *Surg Endosc.* 2019;33(7):2323-31.
26. Norasi H, Hallbeck MS, Elli EF, Tollefson MK, Harold KL, Pak R. Impact of preferred surgical modality on surgeon wellness: a survey of workload, physical pain/discomfort, and neuromusculoskeletal disorders. *Surg Endosc.* 2023;37(12):9244-54.
27. Gutierrez-Diez MC, Benito-Gonzalez MA, Sancibrian R, Gandarillas-Gonzalez MA, Redondo-Figuero C, Manuel-Palazuelos JC. A study of the prevalence of musculoskeletal disorders in surgeons performing minimally invasive surgery. *Int J Occup Saf Ergon.* 2018;24(1):111-7.
28. Razavi S, De EJB. Ergonomics in Urology: Silent Contributor to Burnout Among Women in Urology? *Urology.* 2023;173:222-5.
29. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372:n71.
30. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health.* 1998;52(6):377-84.
31. Nelson E, Kelly D, Ni Bhriain O, Garry F, Clifford AM, Allardyce JM. The effectiveness of community dance in people with cancer: a mixed-methods systematic review and meta-analysis. *Health Promot Int.* 2023;38(4).
32. Hooper P, Jutai JW, Strong G, Russell-Minda E. Age-related macular degeneration and low-vision rehabilitation: a systematic review. *Can J Ophthalmol.* 2008;43(2):180-7.
33. Silverman SR, Schertz LA, Yuen HK, Lowman JD, Bickel CS. Systematic review of the methodological quality and outcome measures utilized in exercise interventions for adults with spinal cord injury. *Spinal Cord.* 2012;50(10):718-27.
34. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ.* 2008;336(7650):924-6.

35. Allespach H, Sussman M, Bolanos J, Atri E, Schulman CI. Practice Longer and Stronger: Maximizing the Physical Well-Being of Surgical Residents with Targeted Ergonomics Training. *J Surg Educ.* 2020;77(5):1024-7.
36. Kraemer B, Seibt R, Stoffels AK, Rothmund R, Brucker SY, Rieger MA, et al. An ergonomic field study to evaluate the effects of a rotatable handle piece on muscular stress and fatigue as well as subjective ratings of usability, wrist posture and precision during laparoscopic surgery: an explorative pilot study. *Int Arch Occup Environ Health.* 2018;91(8):1021-9.
37. Kawahira H, Nakamura R, Shimomura Y, Oshiro T, Okazumi S, Lefor AK. A wearable lower extremity support for laparoscopic surgeons: A pilot study. *Asian J Endosc Surg.* 2021;14(1):144-8.
38. Dalager T, Jensen PT, Winther TS, Savarimuthu TR, Markauskas A, Mogensen O, et al. Surgeons' muscle load during robotic-assisted laparoscopy performed with a regular office chair and the preferred of two ergonomic chairs: A pilot study. *Appl Ergon.* 2019;78:286-92.
39. Cha JS, Athanasiadis DI, Asadi H, Stefanidis D, Nussbaum MA, Yu D. Evaluation of a passive arm-support exoskeleton for surgical team members: Results from live surgeries. *Journal of safety research.* 2024;89:322-30.
40. Hess P, Athanasiadis D, Lee NK, Monfared S, Cleveland PM, Stefanidis D. Preventing Surgeon Work-Related Musculoskeletal Disorders: A Pilot Study of the Comprehensive Operating Room Ergonomics (CORE) Program. *Am J Occup Ther.* 2024;78(5).
41. Hokenstad ED, Hallbeck MS, Lowndes BR, Morrow MM, Weaver AL, McGree M, et al. Ergonomic Robotic Console Configuration in Gynecologic Surgery: An Interventional Study. *J Minim Invasive Gynecol.* 2021;28(4):850-9.
42. Liu S, Hemming D, DeLong JC, Montalvo D, Suzuki T, Reynolds J, et al. Solving the surgeon ergonomic crisis with surgical exosuit. *Surgical Endoscopy and Other Interventional Techniques.* 2017;31(Supplement 1):S44.
43. Fransiak J, Craven R, Mosaly P, Gehrig PA. Feasibility and acceptance of a robotic surgery ergonomic training program. *JSLs.* 2014;18(4).
44. Giagio S, Volpe G, Pillastrini P, Gasparre G, Frizziero A, Squizzato F. A Preventive Program for Work-related Musculoskeletal Disorders Among Surgeons: Outcomes of a Randomized Controlled Clinical Trial. *Ann Surg.* 2019;270(6):969-75.
45. Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics Workshop Improves Musculoskeletal Symptoms in General Surgery Residents. *Journal of Surgical Research.* 2022;280:567-74.
46. Yadav SK, Lal G, Jain SB, Jha CK, Corwin C, Van Gorp B, et al. Indian surgery Trainee's perspective on surgical ergonomics principles and education: A long road ahead. *American Journal of Surgery.* 2023;226(5):735-40.
47. Engelmann C, Schneider M, Kirschbaum C, Grote G, Dingemann J, Schoof S, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: a randomized clinical trial. *Surgical endoscopy.* 2011;25(4):1245-50.
48. Kromberg LS, Kildebro NV, Mortensen LQ, Amirian I, Rosenberg J. Microbreaks in Laparoscopic Appendectomy have No Effect on Surgeons' Performance and Well-being. *J Surg Res.* 2020;251:1-5.
49. Klein M, Andersen LPH, Alamili M, Gogenur I, Rosenberg J. Psychological and physical stress in surgeons operating in a standard or modern operating room. *Surgical laparoscopy, endoscopy & percutaneous techniques.* 2010;20(4):237-42.

50. van Det MJ, Meijerink WJHJ, Hoff C, van Veelen MA, Pierie JPEN. Ergonomic assessment of neck posture in the minimally invasive surgery suite during laparoscopic cholecystectomy. *Surgical endoscopy*. 2008;22(11):2421-7.
51. Veelen MA, Jakimowicz JJ, Goossens RH, Meijer DW, Bussmann JB. Evaluation of the usability of two types of image display systems, during laparoscopy. *Surg Endosc*. 2002;16(4):674-8.
52. Lim AK, Ryu J, Yoon HM, Yang HC, Kim S-K. Ergonomic effects of medical augmented reality glasses in video-assisted surgery. *Surgical endoscopy*. 2022;36(2):988-98.
53. Chan C, Tan YC, Lim EW, Teo J-Y, Lin J, Tan WJ, et al. Evaluating the surgical trainee ergonomic experience during minimally invasive abdominal surgery (ESTEEMA study). *Scientific reports*. 2024;14(1):12502.
54. Nishimoto W, Kawahira H, Shimomura Y, Nishizawa Y, Ito M. A standing posture support device that reduces laparoscopic surgeons' occupational lower limb stress. *Minimally invasive therapy & allied technologies : MITAT : official journal of the Society for Minimally Invasive Therapy*. 2019;28(3):151-6.
55. Haramis G, Rosales JC, Okhunov Z, Mues AC, Badani K, Gupta M, et al. Prospective randomized evaluation of foot gel pads for operating room staff comfort during laparoscopic renal surgery. *Journal of Urology*. 2010;183(4 SUPPL. 1):e424.
56. Rassweiler J, Goetzen AS, Jalal A, Klein J, Hruza M, Schulze M. A new platform improving ergonomy of laparoscopic surgery: Experimental studies and initial clinical evaluation. *Journal of Urology*. 2012;187(4 SUPPL. 1):e347.
57. Unver S, Makal Organ E. The effect of anti-fatigue floor mat on pain and fatigue levels of surgical team members: A crossover study. *Applied Ergonomics*. 2023;110:104017.
58. Franasia J, Craven R, Mosaly P, Gehrig PA. Feasibility and acceptance of a robotic surgery ergonomic training program. *JSLs : Journal of the Society of Laparoendoscopic Surgeons*. 2014;18(4):e2014.00166-e2014.
59. Haramis G, Rosales JC, Palacios JM, Okhunov Z, Mues AC, Lee D, et al. Prospective randomized evaluation of FOOT gel pads for operating room staff COMFORT during laparoscopic renal surgery. *Urology*. 2010;76(6):1405-8.
60. van Veelen MA, Jakimowicz JJ, Goossens RHM, Meijer DW, Bussmann JBJ. Evaluation of the usability of two types of image display systems, during laparoscopy. *Surgical Endoscopy*. 2002;16(4):674-8.
61. Koshy K, Syed H, Luckiewicz A, Alsoof D, Koshy G, Harry L. Interventions to improve ergonomics in the operating theatre: A systematic review of ergonomics training and intra-operative microbreaks. *Annals of Medicine and Surgery*. 2020;55:135-42.
62. Wong SW, Parkes A, Crowe P. Ergonomic interventions to reduce upper limb musculoskeletal pain during robotic surgery: a narrative review. *J Robot Surg*. 2024;18(1):224.
63. Galinsky T, Swanson N, Sauter S, Dunkin R, Hurrell J, Schleifer L. Supplementary breaks and stretching exercises for data entry operators: a follow-up field study. *Am J Ind Med*. 2007;50(7):519-27.
64. Sweeney K, Mackey M, Spurway J, Clarke J, Ginn K. The effectiveness of ergonomics interventions in reducing upper limb work-related musculoskeletal pain and dysfunction in sonographers, surgeons and dentists: a systematic review. *Ergonomics*. 2021;64(1):1-38.
65. Koshy K, Syed H, Luckiewicz A, Alsoof D, Koshy G, Harry L. Interventions to improve ergonomics in the operating theatre: A systematic review of ergonomics

training and intra-operative microbreaks. *Annals of Medicine and Surgery*. 2020;55(February):135-42.

66. Sogaard K, Sjøgaard G. Physical Activity as Cause and Cure of Muscular Pain: Evidence of Underlying Mechanisms. *Exerc Sport Sci Rev*. 2017;45(3):136-45.
67. Zebis MK, Andersen CH, Sundstrup E, Pedersen MT, Sjøgaard G, Andersen LL. Time-wise change in neck pain in response to rehabilitation with specific resistance training: implications for exercise prescription. *PLoS One*. 2014;9(4):e93867.
68. Strom V, Roe C, Knardahl S. Work-induced pain, trapezius blood flux, and muscle activity in workers with chronic shoulder and neck pain. *Pain*. 2009;144(1-2):147-55.
69. Jensen MJ, Liao J, Van Gorp B, Sugg SL, Shelton J, Corwin C, et al. Incorporating Surgical Ergonomics Education into Surgical Residency Curriculum. *Journal of Surgical Education*. 2021;78(4):1209-15.
70. Dairywala MI, Gupta S, Salna M, Nguyen TC. Surgeon Strength: Ergonomics and Strength Training in Cardiothoracic Surgery. *Semin Thorac Cardiovasc Surg*. 2022;34(4):1220-9.
71. Gabrielson AT, Clifton MM, Pavlovich CP, Biles MJ, Huang M, Agnew J, et al. Surgical ergonomics for urologists: a practical guide. *Nature reviews Urology*. 2021;18(3):160-9.
72. Cardenas-Trowers O, Kjellsson K, Hatch K. Ergonomics: making the OR a comfortable place. *International urogynecology journal*. 2018;29(7):1065-6.
73. Dalager T, Højmark A, Jensen PT, Sjøgaard K, Andersen LN. Using an intervention mapping approach to develop prevention and rehabilitation strategies for musculoskeletal pain among surgeons. *BMC public health*. 2019;19(1):320-.

PAPER II – RCT PROTOCOL PAPER

STUDY PROTOCOL

Open Access



Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA)

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Abstract

Background Surgeons are in high demand due to the ageing population's increased need for surgery. However, the high prevalence of musculoskeletal pain (MSP) threatens their career longevity. While improving intraoperative ergonomics is crucial, physical exercise training is also widely used in managing MSP. The objective is to investigate the added effectiveness of intelligent physical exercise training (IPET) when combined with intraoperative ergonomic recommendations (ERGO), compared to ERGO alone, in reducing MSP among abdominal and pelvic surgeons.

Methods This pragmatic, multicenter, 20-week, superiority, open-label randomized controlled trial (RCT) is conducted in two phases. Phase 1 is a 3-month ergonomic educational period (ERGO) delivered to all participants. Phase 2 is the RCT, where participants are randomized 1:1 to ERGO (control) or ERGO + IPET (intervention). ERGO provides recommendations for operating room (OR) ergonomics, including posture and microbreaks, displayed in and around ORs. IPET prescribes 50 min of individualized weekly exercise, tailored to MSP, job profile (sedentary, walking/standing, or heavy work), physical capacity, and health risk indicators, and is delivered via a mobile application. Eligible surgeons specialize in gynecology, urology, and colorectal surgery and perform ≥ 4 h/week of abdominal or pelvic surgery (robot-assisted, laparoscopic, or open, excluding vaginal surgery), and complete the Phase 1 questionnaire. Surgeons advised against exercise by their GP are excluded. Participants are recruited from regional and academic

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hospitals in Denmark and North America. Enrollment begins with completion of the ERGO survey and consent in the baseline questionnaire. Recruitment started 13 December 2023, with a target sample size of 83. The primary effect of interest is the between-group difference in MSP intensity (0–10 numeric rating scale) at 20 weeks in the body part reported as most painful at baseline, analyzed using a linear mixed model with baseline MSP as covariate. Harms include increases in MSP or injury, though these will not be systematically collected. Participants and research staff are not blinded. Outcome interpretation will be blinded to group allocation.

Discussion This trial addresses a gap in strategies to mitigate MSP among surgeons by combining ergonomics recommendations with app-delivered IPET. Findings may inform strategies to improve surgeon well-being and reduce future workforce shortages.

Trial registration Clinicaltrials.gov, NCT06112106. Registered on October 4, 2023.

Keywords Exercise, Ergonomics, Microbreak, Rehabilitation, Musculoskeletal pain, Workplace intervention, Surgeon, Surgical ergonomics

Background

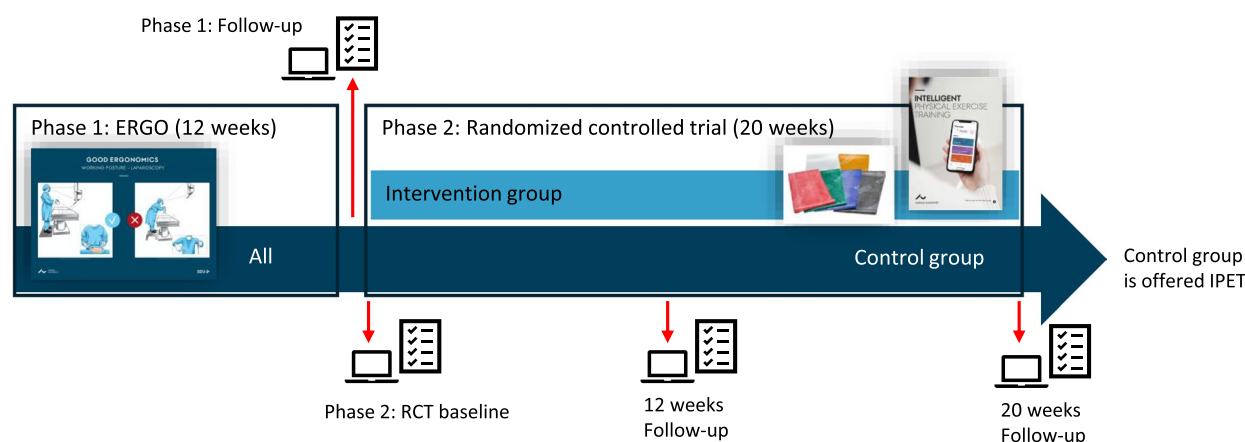
Surgeons are highly specialized healthcare professionals who undergo many years of extensive training. Given the rising demand for both the number and complexity of surgeries due to an aging population and an increase in cancer-related procedures, there is a societal imperative that they remain healthy and fit for work throughout their careers [1]. However, musculoskeletal pain (MSP) is highly prevalent: a 2022 meta-analysis among gynecologists and global survey among urologists reported MSP prevalences of 82% and 81%, respectively [2, 3], with more recent data indicating no substantial change among gynecologist [4]. Similarly, a multi-specialty international survey from 2023 among laparoscopic surgeons reported a 90% pain prevalence [5], consistent with a 2019 survey among surgeons in the same specialties included in the present protocol [6, 7]. In that study, most participants reported multisite pain (two or more painful body sites), with the highest pain intensities reported in the neck, lower back, upper back, and shoulders [6, 7]. Multi-site pain has been shown to negatively affect work (21%), leisure time activities (40%), and sleep (27%) [7], and in up to 12% of surgeons it may lead to practice restrictions or early retirement [2, 8].

Working postures that involve awkward, static, and repetitive movements with high precision demands are common for surgeons and are well-known risk factors for MSP [9, 10]. The existing literature calls for better ergonomics in the operating room (OR) to mitigate what has been called “the impending epidemic” of surgeon MSP [8, 11]. Although ergonomic principles and practices have been on the agenda for decades, awareness and adoption of these practices among surgeons remain limited [11–14]. In a small study among general surgery residents, all residents reported little to no ergonomics knowledge with 68% reporting that ergonomics was rarely discussed in the operating room (OR) [15]. In a survey among US medical schools,

98% reported their students will receive less than 3 h of ergonomic education [16], which is supported by a survey among directors of surgical and interventional medical specialties in the USA where 1.5% provided formal surgical ergonomics education (SEE) and 25.4% provided informal SEE [17].

Studies indicate that greater understanding of surgical ergonomics is associated with a higher degree of application in practice, with up to 93.3% of those who are aware of ergonomic information reporting its application [11, 18]. Thus, sound ergonomic knowledge should be an integral part of any job, including performing surgery. Nevertheless, solely focusing on the surgical ergonomics in the OR, i.e., the external work demands created by the physical surroundings, may only be part of the solution and the evidence on its effects on surgeons' musculoskeletal health is limited [19]. In contrast, the evidence on the benefits of physical exercise training in rehabilitation and prevention of MSP is well-supported [20–22]. Maintaining overall fitness and muscle strength appears to be protective against MSP when pursuing a career in surgery, as 66% of surgeons who exercise regularly (≥ 4 times per week) reported no pain, compared to 34% of those exercising less. Similarly, greater handgrip strength was protective, with MSP prevalence of 79% among surgeons with above-average strength versus 93% among those with below-average strength [6, 23].

Tailored preventive and rehabilitative physical exercise training may be even more beneficial than solely optimizing surgical ergonomics and engaging in general exercise [21]. Thus, intelligent physical exercise training (IPET) was designed to be tailored according to the individual's occupational exposure, health status, physical capacity, and MSP [24]. The IPET program has demonstrated positive effects on workers' health and MSP in various occupational groups with high physical work demands [22]. However, its effects on MSP rehabilitation and prevention among surgeons remain unknown.



ERGO = ergonomic recommendations, RCT= randomized controlled trial, IPET = Intelligent Physical Exercise Training

Fig. 1 Pre-trial and trial time-line with assessment time points

Objective

The objective is to investigate the added effectiveness of individualized physical exercise training (IPET) when combined with intraoperative ergonomic recommendations (ERGO), compared to ERGO alone, in reducing MSP among abdominal and pelvic surgeons. Our hypothesis is that ERGO alone (control group) may prevent or lead to a slight, but not clinically relevant, reduction in MSP, and that the combination of IPET + ERGO (intervention group) will have a synergistic and clinically relevant effect, resulting in a greater reduction in MSP compared to ERGO alone.

Methods: population, interventions, outcomes

Trial design

This protocol follows the Standard Protocol Items: Recommendations for Interventional Trials guidance for reporting protocols for clinical trials (SPIRIT) [25] and adheres to the Template for Intervention Description and Replication (TIDieR) checklist [26]. The trial was registered prospectively at Clinicaltrials.gov (NCT06112106), which meets the WHO Trial Registration Data Set standards, and will adhere to the declaration of Helsinki. The trial protocol and statistical analysis plan (SAP) will be available at ClinicalTrials.gov (NCT06112106).

The trial is designed as a multicenter, superiority, open-label block-randomized controlled trial (RCT) with two parallel arms allocated in a 1:1 ratio, with a 20-week intervention period with baseline, 12-, and 20-week outcome assessments (Fig. 1). Two surgeons, representing the target study population, contributed to the trial design, trial conduct, and participated in the reporting of results.

Participants are recruited from hospital departments specializing in gynecology, urology, and colorectal surgery at selected Danish and North American academic medical centers. Detailed site information is available on Clinicaltrials.gov. Recruitment and baseline assessments commenced in December 2023 and is expected to run until March 2026 or until the required sample size is attained. Figure 2 illustrates the flow of participants.

Population

Eligible persons are primary and assisting surgeons from gynecology, urology, and colorectal surgery, who perform a minimum average of 4 h per week of robot-assisted laparoscopy (RAS), laparoscopy (LAP), or open surgery (OPEN) in the abdomen or pelvis (excluding vaginal surgery), and who complete the Phase 1 follow-up questionnaire. Surgeons whose general practitioner advises against performing physical exercise training are ineligible to participate in the trial.

The intervention

The intervention consists of two phases: a pre-trial educational phase (Phase 1) and the trial phase (Phase 2) (Figs. 1 and 2).

Phase 1: pre-trial education on good ergonomics

The first phase begins 12 weeks before the trial and is initiated with a presentation on *Good Ergonomics* (ERGO)—recommendations on surgical ergonomics—delivered by a member of the research team. The goal is to establish a basic understanding of surgical ergonomics and its underlying rationale, forming the basis for the “standard condition,” and to create awareness of the project.

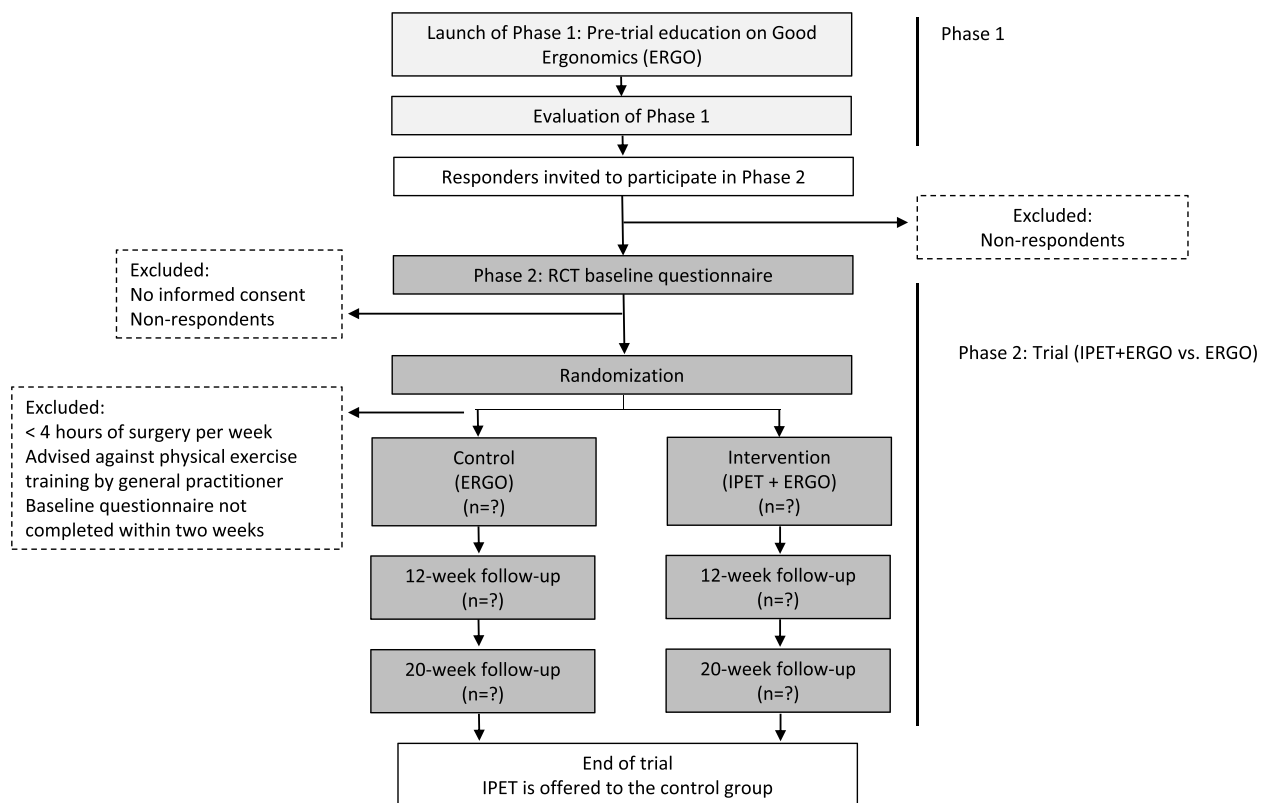


Fig. 2 Flow of participants from the pre-trial phase through to the end of the trial

ERGO has two overall elements: recommendations on (1) improving work postures in the OR, i.e., adjusting monitor height, adjusting the robotic console to maintain a neutral position of the joints, and (2) performing intraoperative microbreaks with stretching exercises.

ERGO was informed by a systematic literature review with the aim to elucidate the effects of ergonomic practices within the OR on surgeons' musculoskeletal health and workload (PROSPERO registration no. CRD42022354609; findings will be published separately), a review of surgical ergonomics [27], and general best-practice ergonomic guidelines from the Danish Working Environment Authority.

Improved surgical ergonomics would benefit participants by reducing physical demands during surgery, such as static, awkward, and constrained postures, which are known risk factors for developing MSP [10]. Figure 3A illustrates an ERGO poster with recommendations for LAP surgeons on maximal abduction of shoulders, optimizing the height of the table, placement of the monitor, and the angle between the instruments. Additionally, two similar posters provide surgeons with ergonomic recommendations during OPEN and RAS (Additional Figs. 3B and C).

The ERGO posters will be displayed in or near the OR, in OR break rooms, in the OR-Stretch web-app, in locker rooms, and in respective departments, with local variations. The posters include a QR code linking to short videos that explain the importance of OR ergonomics and microbreaks in preventing MSP. Additionally, during the initial three weeks, support for introducing ERGO was available approximately twice per week at some participating departments.

The second ERGO element is the recommendation to perform regular (at least every 60 min) intraoperative microbreaks with stretching exercises. Often, surgeons have limited ability to take a break at their discretion and may overlook early signs of fatigue. To address this, microbreaks are short structured intraoperative breaks with guided dynamic stretching exercises targeting the upper body and trunk to lower discomfort and fatigue, stress, and maintain focus [28–30].

The microbreaks are guided either by Mayo Clinic's OR Stretch web app [31, 32], or by a locally adapted Danish-language audio version, accessible via a QR code. The microbreak lasts approx. 90 s. At the beginning of a surgical day, the OR team is encouraged to agree on the planned frequency of microbreaks for that day's surgeries, e.g., at 60-min intervals or at a surgically convenient



Fig. 3 Good Ergonomics posters. **A** Laparoscopic surgery **B** Open surgery **C** Robot-assisted surgery [27]



throughout the trial period. This is considered “standard condition” and represents the control group. In the intervention group, ERGO is combined with IPET, a physical exercise training concept with tailored evidence-based exercises that should be performed for a total of 50 min per week, either alone or with other intervention-group colleagues. IPET considers individual occupational exposure (e.g., sedentary, walking/standing/or heavy work), health status, physical capacity in terms of fitness, strength, and balance, as well as MSP prevalence and intensity. The theory behind IPET is that physical exercise training has a pain-relieving effect, with aerobic exercise providing acute benefits and strength training offering long-term effects [24, 33]. Further, as a result of improved muscular strength and endurance, the relative load during work is reduced, leading to less strain and less accumulated fatigue during surgery. Ultimately, this should result in a decrease in MSP [33]. The weekly 50 min IPET can be performed in one session or divided into 2–5 shorter sessions with the same effect [34].

Intelligent physical exercise training

Originally, intelligent physical exercise training (IPET) was prescribed based on physiological measurements that determined the training categories (aerobic, strength, or functional training) [24]. Over decades of research, the IPET concept evolved into a mobile application, the *Intelligent Motion* app (hereafter referred to as “the app”) which serves as the main component of the intervention in this trial. The app was pilot-tested among different populations, including health workers, and university employees. The self-assessed measurements and their cut-points leading to IPET exercise prescription are described in Table 1 (modified from [35], under the terms of the Creative Commons Attribution License). Each intervention group participant will receive access to their individualized IPET program through the app. Download instructions and a unique access code will be sent via e-mail to ensure that the app cannot be accessed or shared by other trial participants.

Each participant’s 50-min IPET program will have 20 min of aerobic exercise training allocated to target their physical work demands. Depending on their profile, such as sedentary work, walking/standing, or physically heavy, the aerobic component prescribed will consist of moderate- to high-intensity aerobic training (14–15 on the Borg 6–20 scale [36], which corresponds to 77–95% of $\text{VO}_{2\text{max}}$ [37]), high-intensity interval aerobic training (17–19 on the Borg 6–20 scale (>96% of $\text{VO}_{2\text{max}}$) with rest breaks maintained at an intensity of 8–0 (<60% $\text{VO}_{2\text{max}}$)) with functional training, or overall muscle endurance training, respectively.

The remaining 30 min will consist of a combination of aerobic-, strength- and functional training depending on individual profile [24]. Additional aerobic- or functional training can be prescribed based on physical activity profile. Any MSP will lead to the prescription of strength training for the affected body part. All participants will start with two sets of 15 repetitions, with the number of repetitions decreasing as the load is increased. See Table 2 for the strength training progression scheme.

The training load will be adjusted using elastic resistance bands (Theraband). Participants will receive a set of four elastic bands with varying levels of tension/resistance from “very easy” to “hard” (red, green, blue and black). Guidance on selecting the appropriate elastic band and on progression/regression is available in the app, along with access to an IPET knowledge bank (Fig. 5A). Figure 5B illustrates an example of an IPET program. Training progression and competition with colleagues can be tracked in the app by creating teams and inviting colleagues to join a training community via a shared code (Fig. 5C). Only colleagues in the intervention group have access to the app and can use the code.

No personal health data will be shared within the app beyond team membership and exercise progress.

Participants are encouraged to complete the exercises in their leisure time or, if possible, during working hours [24, 38–40]. The app will track user interactions, including completed training minutes per week, the frequency of app usage, and the content accessed.

Outcomes

The primary effect of interest is the between-group difference in worst MSP intensity at 20 weeks, assessed using a 11-point numerical rating scale (NRS) for the body part with the highest reported pain intensity at baseline. In cases where multiple body parts have equal pain intensity, the body part with the longest duration of pain will be selected. If both pain intensity and pain duration are equal across painful body parts, the body part baseline NRS score will be selected according to the most prevalent painful body part among Danish surgeons [7]. All outcomes are self-reported and validated questionnaires will be used where possible.

The secondary outcomes include pain case status, MSP last 7 days, MSP duration, MSP consequences, general health, burnout, and workability (Table 3). The following descriptive variables will also be collected: working conditions, use of pain medication, physical activity profile, physical resources, time spent on physical activity, and compliance with ERGO. At 20-week follow-up, participants in the intervention group will be asked to rate the app overall, its usability, and their likelihood of recommending it.

Participants may experience mild, short-term muscle soreness immediately after a session and for up to 72 h. This is common and a harmless and expected response to exercise. Although increases in musculoskeletal pain (MSP) or injury are also considered harms, such events have been rare in previous studies of similar interventions, with no serious side effects reported [20]. As these outcomes are not anticipated, they will not be systematically recorded.

Sample size

The prevalence of MSP among surgeons is reported to be around 90% [6, 7], with many experiencing multisite pain and a pain intensity of 3 to 4 on a 11-point NRS. An MSP intensity ≥ 3 NRS points is considered the threshold for clinically important pain [51], and defines a pain case in this trial. A pain reduction of 30–40% (corresponding to approx. 1.5 NRS points) is considered the minimum clinically important difference (MCID) [52], and this level of improvement has been demonstrated in comparable trials investigating IPET [53–55]. Therefore, the targeted

Table 1 Cut-points leading to prescription of IPET in the Intelligent Motion app

Variable		Measurement	Description Model	Cut-point/Group allocation
Job profile	Occupational exposure category	Self-report	<i>How would you categorize the physical demands in your main job?</i> (1) Mainly sedentary work that does not require physical exertion (2) Work largely performed while standing or walking (3) Standing or walking work with some lifting and/or carrying activities (4) Heavy or fast-paced work, which is strenuous	1. Sedentary: moderate to high intensity aerobic training 2. Standing/walking: high intensity interval aerobic training +function training 3. + 4. Physically heavy: whole body muscle endurance training
	Physical capacity profile	Cardiovascular fitness	Self-report	<i>How would you score your aerobic capacity compared to others of your own age and sex?</i> Assessed on a 0–10 numerical rating scale (NRS) ranging from as poor to as good as possible
Health profile	Muscle strength	Self-report	<i>How would you score your strength capacity compared to others of your own age and sex?</i> Assessed on a 0–10 NRS ranging from as weak to as strong as possible	Responses below 5 (corresponding to average) lead to prescription of extra all-round strength training
	Balance and function	Self-assessment	Self-assessed standing time on non-dominant leg with the arms crossed over the chest (hands on the shoulders). Three trials are given	If the individual loses balance before reaching 30 s, functional training is prescribed
	Body mass index	Self-assessed or self-report	Assessed as an individual's weight in kilograms divided by the square of height in meters	A body mass index above 25 leads to the prescription of extra aerobic training
	Musculoskeletal disorders	Self-report	<i>For how many days in total have you had (specific body part) pain during the last 3 months/7 days?</i> <i>If symptoms have been prevalent for one or more days, a follow up question is asked about average pain intensity. Please indicate your level of (specific body part) pain (0–10 NRS) within the last 3 months/7 days</i>	Any symptoms lead to prescription-specific strength training for the body part. If an individual has symptoms in more than two (tree) body parts, the pain intensity guides the prioritization

NRS numerical rating scale.

The text in italics represents the questions being asked in the app to design the IPET program.

Table 2 IPET strength training progression scheme. *RM* repetition maximum

Week	No. of sets per exercise	No. of repetitions (RM load)
1	2	15
2	2	15
3	3	15
4	2	12
5	3	12
6	4	12
7	2	10
8	3	10
9	4	10
10	2	8
11	3	8
12	4	8
13	4	8
14	2	8
15	3	8
16	4	8
17	4	8
18	4	8
19	4	8
20	4	8

MSP reduction is a between-group difference of 1.5 NRS points [52].

To detect this difference in MSP intensity between the intervention and control groups, a two-sided independent sample *t* test was used for the sample size calculation. With a standard deviation of 2.0 NRS points, a power of 80%, and a significance level (alpha) of 0.05; 58 participants in total are required. To account for a drop-out rate of up to 30%, the total sample size is 83 participants. The sample size calculation was performed using Stata (version 17).

Methods: assignment of interventions

Sequence generation and allocation concealment mechanism

Participants will be randomly allocated to either the control or intervention group with a 1:1 allocation ratio. The randomization will follow a computer-generated sequence with permuted and random block sizes of 4, 6 and 8 [56], stratified by pain case status. The allocation sequence list will be prepared prior to study start by a central REDCap data manager who is not involved in the trial. A member of the research group will initiate randomization by clicking a “randomize” button in the REDCap system, which will then automatically allocate

participants to a group. Participants will receive automated e-mails informing them of their group status (e.g., “Congratulations, you have been enrolled in the intervention group”) along with guidance on how to download the app. The control group participants will receive a message that encourages them to continue with ERGO for the next 20 weeks and that they will be offered IPET after the trial ends.

Due to the nature of the intervention, neither the participants nor members of the research team will be blinded to group assignments.

Methods: data collection, data management, and analysis

Data collection

Data will be entered directly into REDCap by participants (survey responses), and REDCap automatically performs range checks, branching logic, and validation rules to minimize entry errors. Each participant is assigned a unique study ID to ensure de-identification. Data will be collected at four time points (Fig. 1). The first data collection occurs at the end of Phase 1, where surgeons will be asked about their awareness of the ERGO recommendations and the extent to which they have applied it in the OR. The questionnaire will also address topics such as the presence, location, and duration of MSP experienced while operating in the past three months. Further topics include awareness of and adherence to ERGO, actions taken to reduce discomfort while operating, surgical modalities used in the past three months, and whether MSP influences the selection of surgical modality. After completing the Phase 1 follow-up questionnaire, participants are invited to complete the Phase 2 RCT baseline questionnaire during which electronic informed consent to participation and data handling is obtained. Thus, only those who complete the Phase 1 follow-up questionnaire can participate in the trial. The baseline questionnaire constitutes the second data collection point. The third and fourth data collection points occur at 12 and 20 weeks after baseline. The data collection instruments can be found in the supplementary material.

Data management

Data from the online questionnaires is stored on a secure REDCap database with access limited to key research group personnel. Participants’ name and personal identification numbers will not be collected.

During the trial, data from the IPET app will be collected and stored securely by the app developer, 50 Minutes Aps, using Amazon Web Services storage facility in Germany. All data collected will be de-identified before processing, and results will be reported in aggregate at the group level. Data handling complies with Danish

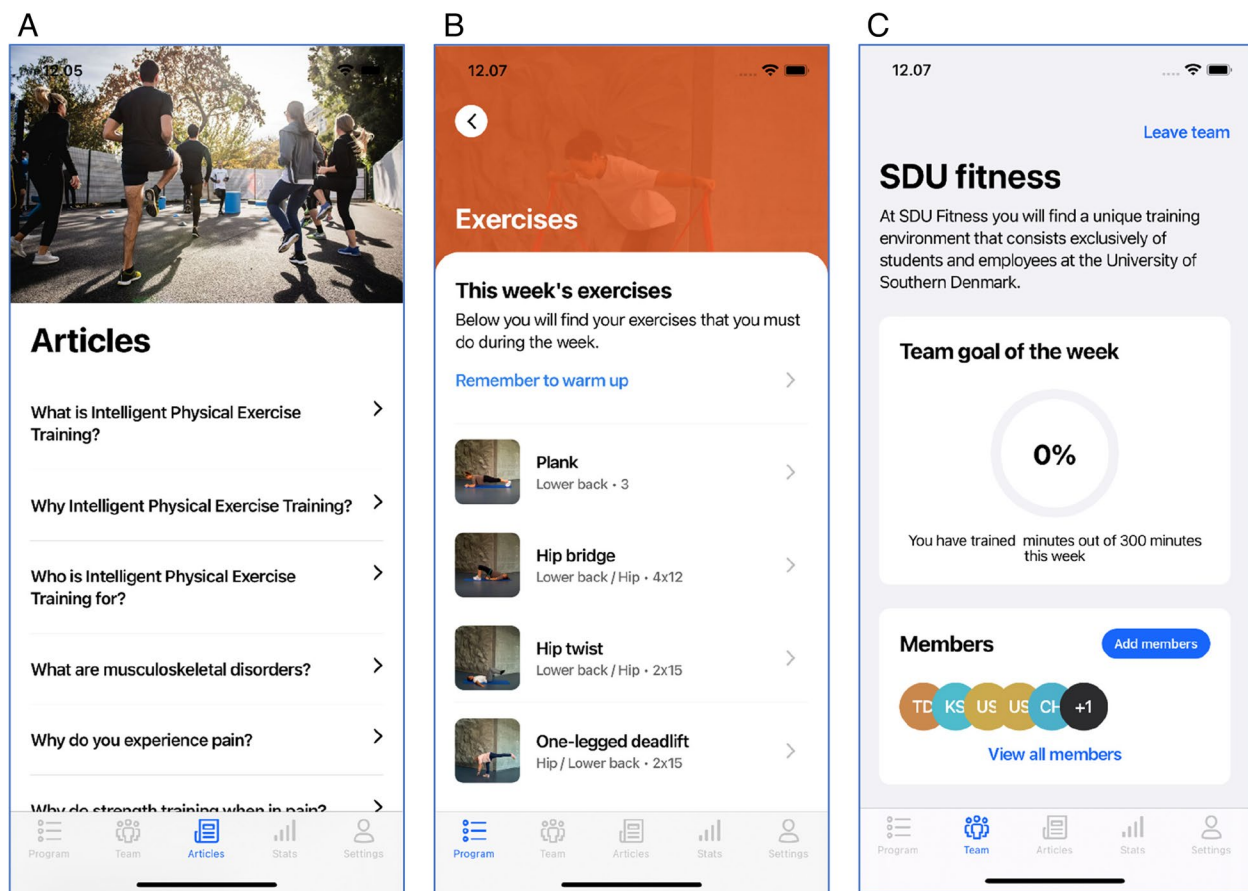


Fig. 5 App screenshots. **A** App knowledge bank. **B** Screen shot with an example of an IPET program. **C** Training community

and American legislation on the protection of personal data. Primary research data and related materials will be securely stored at Aarhus University for at least 5 years following project completion, in accordance with university policy. Personal data will only be retained as long as necessary for the research purpose, after which it will be either anonymized, securely archived, or deleted. A detailed Data Management Plan describing procedures for coding, quality control, and security is available from the corresponding author upon reasonable request.

Data access

Access to the final trial dataset will be restricted to the study investigators at Aarhus University and collaborating institutions. In accordance with Aarhus University's data protection policies and GDPR regulations, only de-identified data will be shared. External researchers may be granted access to anonymized datasets upon reasonable request, subject to approval by the principal investigator and relevant institutional bodies (and their Institutional Review Boards), and following the completion of a data sharing agreement.

Any significant protocol modifications, such as changes to eligibility criteria, outcomes, or analyses, will be promptly communicated to all relevant stakeholders through revised documentation.

Participant adherence and study retention

The trial approach is highly pragmatic, making it voluntary for participants to apply ERGO throughout both phases. No restrictions on concomitant care were imposed. This pragmatic approach also applies to participants in the intervention group, who are asked to download and follow the IPET instructions provided in the app. The app includes built-in features of progress notifications, and reminders to complete exercises, but no direct supervision. Participants may withdraw from the trial at any time by contacting the corresponding author. All cases of attrition, including withdrawn consent, will be recorded with reasons for withdrawal or refusal to provide follow-up data when available. To maximize retention and ensure complete follow-up data, automatic e-mail reminders will be sent up to two times: 7 and 14 days after the initial questionnaire distribution. Periodic

Table 3 Summary of data collection variables and time points

	Scale/categories	Data collection instrument (unit)	Assessment time point		
			Baseline	12 weeks	20 weeks
Primary outcome					
Pain intensity (3 months) <i>Median/mean [SD/IQR]</i>	11-point ordinal NRS scale (0 = no pain, 10 = most intense pain) the past three months in; neck, shoulders, elbows/arms, wrists/hands, upper back, lower back, hips, knees, ankle/feet	The Nordic Musculoskeletal Questionnaire (modified) [41]*	x	x	x
Secondary outcomes					
Pain case status <i>Proportion</i>	Pain case (NRS ≥ 3) Non-Pain case (NRS < 3)	Self-constructed categories			
Days with musculoskeletal pain (past 3 months) <i>Proportion</i>	0 days 1–7 days 8–30 days More than 30 days but not every day Every day	The Nordic Musculoskeletal Questionnaire (modified) [41]*	x	x	x
Pain intensity (7 days) <i>Proportion</i>	11-point ordinal NRS scale (0 = no pain, 10 = most intense pain) the last 7 days in; neck, shoulders, elbows/arms, wrists/hands, upper back, lower back, hips, knees, ankle/feet	The Nordic Musculoskeletal Questionnaire (modified) [41]*	x	x	x
Days with leisure or work affected by pain <i>Proportion</i>	0 days 1–7 days 8–30 days More than 30 days but not every day Every day	The Nordic Musculoskeletal Questionnaire (modified) [41]*	x	x	x
Use of pain medication <i>Proportion</i>	Daily ≥ 1 time/week ≥ 1 time/month Rarely/never	Self-constructed questions	x	x	x
General health <i>Median/mean [SD/IQR]</i>	Scored 0 to 100 points with higher scores indicating a better health status	12-item short form (SF-12) [42]	x	x	x
Personal and work-related burnout <i>Proportion</i>	Scores range from 0 to 100, where < 50 indicates no/low burnout, 50–74 moderate burnout, 75–99 high burnout, and 100 severe burnout	Copenhagen Burnout Inventory (modified) [43, 44]a	x	x	x
Work ability <i>Median/mean [SD/IQR]</i>	Scores range from 7 to 49 with higher scores indicating better work ability	Work Ability Index (modified) [45, 46]b	x	x	x
Descriptive variables					
Moderate to vigorous physical activity <i>Proportion</i>	Less than 30 min 30–89 min 90–149 min 150–299 min 300 min or more	Self-constructed questions inspired by the WHO physical activity recommendations [47]	x	x	x
Physical activity level during leisure time <i>Proportion</i>	Physically inactive Some light physical activity Regular physical activity and training Regular hard physical training for competitive sports	Saltin-Grimby Physical Activity Level Scale [48]	x		

Table 3 (continued)

	Scale/categories	Data collection instrument (unit)	Assessment time point		
			Baseline	12 weeks	20 weeks
Physical resources compared to peers <i>Median/mean [SD/IRQ]</i>	Aerobic fitness, strength, balance 11-point ordinal NRS scale from 0 to 10 (0 = weak/poor, 10 = strong/good)	Strøyer self-reported physical resources scale (modified) [49] ^a	x	x	x
Working conditions <i>Median/mean [SD/IRQ]</i> <i>Proportion</i>	Surgical specialty (colorectal, gynecology, urology, other) Weekly working hours as primary and assisting surgeon	Self-constructed questions	x		
Compliance with ERGO recommendations <i>Proportion</i>	Never Rarely Sometimes Most of the time Always Don't know	Self-constructed questions		x	x
Compliance with IPET <i>Median/mean [SD/IRQ]</i>	No. of IPET minutes performed per week (average)	Self-constructed questions			x**
Rating of the IPET app <i>Proportion</i>	An overall rating of the app, usability, and likelihood of recommending it will be rated from 1 to 5 with a higher score indicating a better rating	Self-constructed questions			x**

All outcomes will be assessed at baseline, 12 and 20 weeks after intervention start. ^aA modified version of the Nordic Musculoskeletal Questionnaire about the locomotive organs [41] will be used with the 12-month prevalence replaced by a 3-month prevalence, and in case of any prevalence, the intensity of the musculoskeletal trouble will be assessed by an 11-point NRS scale (0 = no pain, 10 = most intense pain). ^{**} Intervention-group only.

^a Strøyer's self-assessed physical fitness scale will be used in a modified version with two of five domains of fitness excluded (endurance and flexibility) [49]

^{az}A modified version of The Copenhagen Burnout Inventory will be used with one of three domains excluded (clinician burnout) [43]

^bThe Work Ability Index will be modified by collapsing the list of 14 diseases in item no. 3, into five categories (problems due to an earlier accident, musculoskeletal disease, cardiovascular disease, respiratory disease, and depression or other mental illness) [50]

The Saltin Grimsby physical activity level scale [48], and the SF-12 [42] will be used with no modifications.

remote monitoring of data collection will be conducted via REDCap.

Statistical methods

The primary outcome variables are MSP at 12 and 20 weeks. The primary analysis will be conducted according to the intention-to-treat principle using a linear mixed model, with MSP at weeks 12 and 20 forming the dependent variable. The model will include time (12 weeks, 20 weeks), group allocation (intervention vs. control), and a time×group allocation interaction as fixed effects with baseline MSP intensity value as covariate. Random intercepts for participants and randomization blocks will be included to account for within-person correlation and clustering induced by block randomization. The primary effect of interest is the treatment-group difference at 20 weeks. Results will be presented with corresponding 95% confidence intervals. A two-sided significance level of 0.05 will be used for all statistical tests. Missing data will be handled under the missing-at-random assumption, inherent to the mixed-model approach, and the extent of missingness will be described by trial arm and key baseline characteristics.

Details of additional analyses are provided in the SAP, which will be made available on Clinicaltrials.gov before the completion of data collection and the start of analysis. To reduce the risk of biased interpretation of results, a blind interpretation will be conducted [57]. The procedure will involve drafting two interpretations based on a review of the primary outcome data, with groups arbitrarily labeled A and B. Interpretation 1 assumes that A is the intervention group and B the control group, while interpretation 2 assumes the reverse. After agreeing on both interpretations, the randomization code is broken, and the correct interpretation is selected.

Statistical analyses will be conducted using Stata, version 17 (StataCorp LLC, College Station, TX, USA) [58].

Monitoring

No independent data monitoring committee will be established, as the trial involves low-risk, non-invasive interventions (ergonomic education and structured exercise training) with no anticipated serious adverse events. Mild, short-term muscle soreness may occur but is considered an expected and harmless response to exercise. Safety will be monitored continuously by the study investigators, and any adverse events will be reported to the institutional ethics committee in accordance with regulatory requirements.

No interim analyses are planned, and no formal stopping guidelines have been established, as the intervention is considered low-risk and the trial duration is relatively short.

Discussion

This protocol describes a pragmatic trial investigating the effectiveness of IPET in addition to ERGO in reducing MSP among abdominal and pelvic surgeons at regional and academic medical centers in Denmark and the USA. The trial combines two interventions commonly investigated in other fields—ergonomic interventions and tailored physical exercise training—to enhance the evidence base for strategies aimed at preventing or rehabilitating surgeon MSP. Such pain is associated with fatigue and decreased surgical accuracy [29], burnout [59, 60], sick leave [61], and early retirement [8, 62].

Evidence from ergonomic and exercise interventions

Previous ergonomic interventions have focused on optimizing OR ergonomics and reduce surgeons' physical strain during operations. These interventions have included ergonomic lectures or training [15, 63, 64], posture improving strategies [65–67], intraoperative micro-breaks [28–30, 68], devices to reduce muscle activation [69, 70], and pre-and post-operative stretching exercises [71]. Despite the sound biomechanical rationale behind these studies and their promising findings, most studies are primarily observational in nature. As a result, their impact on reducing MSP remains unclear due to methodological limitations such as the lack of control groups, and infrequent or short follow-up periods between pre- and post-intervention outcome assessments, and the small sample sizes. Investigating the effects of ergonomic recommendations within a rigid study design, as the one proposed in this protocol, may offer a clearer picture of the effectiveness.

In contrast, strong evidence from systematic reviews supports workplace strength training as an effective strategy for reducing MSP among physically demanding professions [21, 72], including health care workers, nurses, and hospital employees. As strength training is a core component of IPET, the program has likewise demonstrated positive effects among individuals with existing MSP, including those in occupations with pain profiles similar to surgeons [39, 53–55, 73]. Our trial is among the first to rigorously combine tailored strength training offered by IPET with ergonomic recommendations in this population. This combined approach may generate synergistic effects for mitigating surgeon MSP.

Methodological considerations

This trial protocol proposes a pragmatic randomized controlled design, which enhances external validity. The participating centers comprised regional and academic hospitals in Denmark and North America where study

participants were employed; however, it is not known whether these centers are representative of the broader population of surgeons. Several other methodological considerations warrant discussion.

Eligibility criteria and participant inclusion

The overall pragmatic approach in this trial may impact internal and external validity in different ways, serving both as a limitation and a strength. For example, the eligibility criterion requiring a minimum average of 4 h of surgery per week was set arbitrarily. This threshold aimed to ensure a sufficient participant pool, while ensuring sufficient surgical exposure (case load/surgery time). A higher threshold might have excluded relevant surgeons, whereas a lower threshold might have included surgeons with insufficient surgical exposure.

The intervention is designed as a workplace-initiated intervention to manage MSP, and is applicable to all surgeons, regardless of current pain status. However, including participants without MSP may reduce the observable contrast in the primary outcome. Therefore, randomization is stratified by pain case status to enable analysis of the entire sample and of those reporting baseline pain.

App-based delivery and supervision

Previous IPET studies allowed workers to perform IPET during working hours, often with some degree of supervision [39, 53–55]. In contrast, the present trial delivers IPET via a mobile app, using elastic resistance bands for individualized, unsupervised training. This format offers flexibility, allowing surgeons to engage in IPET in their leisure time, or in the downtime between surgical cases, as there is the option to split the weekly 50 min of IPET into shorter sessions. This flexibility is intended to facilitate the integration of IPET into daily life. However, the absence of direct supervision, aside from the app-based support features, may hinder the efficacy of intervention delivery. Although this concern did not emerge among office workers who obtained comparable outcomes with or without supervision [34], these findings may not directly translate to surgeons. Nevertheless, a recent systematic review found that mobile app-interventions with tailored physical exercise programs reduced MSP by 1.4 points (95% CI: 0.6 to 2.2) on a 0–10 NRS [74]. This reduction in MSP aligns with the minimum clinically important difference (MCID) defined in the present trial, supporting the potential effectiveness of the app-based delivery model despite the absence of direct supervision.

Self-reported outcomes and measurement limitations

The pragmatic approach of the trial also extends to outcome data collection, which relies solely on online

questionnaires. Unlike previous IPET trials that used objective physical measurements such as relative $\text{VO}_{2\text{max}}$, muscle strength tests, body fat percentage, and blood pressure [35], this approach saves time and resources for participants and researchers. It also tests the scalability of delivering IPET through a mobile app, thereby enhancing external validity. However, it might result in less precise estimates for variables like muscle strength and cardiorespiratory fitness. That said, given that MSP is the primary outcome, and the fact that surgeons are considered to have a high level of health literacy, the risk of bias associated with self-reported data is considered to be minimal.

Risk of contamination and control measures

There is a potential risk of contamination between the intervention and control groups, as participants are individually randomized and are aware of their group assignment. This could potentially reduce the contrast in outcomes between the groups [38, 75], offsetting any observable intervention effects. To address this, the trial was designed so group allocation does not influence interactions within OR: the ERGO guideline applies equally to all surgeons, regardless of allocation, while IPET is intended to be performed during non-operative or leisure time. Although performing IPET during work hours was mentioned as a possibility because that was the protocol in previous IPET trials, surgeons from a previous study have indicated that this is not feasible in their profession [76]. Further, access to the IPET app is restricted through unique activation codes, which are exclusively provided to the intervention group participants. This ensures that app-based teams can only be formed within this group. Additionally, to minimize the risk of protocol deviations, the control group is offered access to IPET after the trial period ends.

In summary, this pragmatic trial is expected to provide valuable insights into the effectiveness of app-delivered IPET as a preventative and rehabilitative strategy for MSP among abdominal and pelvic surgeons. Such findings may represent an important step towards improving surgeon well-being and addressing broader concerns about workforce sustainability and potential surgeon shortages.

Trial status

This is protocol version number 2, dated 2025 June 11. The recruitment began in December 2023, and the recruitment is expected to be completed in October 2025.

Abbreviations

ERGO	Ergonomic recommendations
GP	General practitioner
IPET	Intelligent physical exercise training
MSP	Musculoskeletal pain
NRS	Numerical rating scale
SAP	Statistical analysis plan

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13063-025-09178-x>.

Additional file 1. SPIRIT 2025 checklist of items to address in a randomized trial protocol.

Acknowledgements

Not applicable.

Dissemination policy

The authors intend to disseminate the trial findings through publication in peer-reviewed journals and presentations at national and international conferences. Additionally, the results will be shared with relevant stakeholders and the broader scientific community to ensure widespread accessibility and impact.

Authors' contributions

TD and OM conceived the overall aim of the trial, and OM is the grant holder. HJC, OM, and TD designed the trial. HJC, PTJ, OM, LFS, HN, SH, TD, and KC contributed to the manuscript preparation and trial conduct planning. All authors read and approved the manuscript for publication.

Funding

Financial funding was provided by the Work Environment Research Fund and Aarhus University. The funding sources have not been involved in the design of this trial and will not be part of any execution, analysis, or interpretation of the data, or decisions to publish results.

Data availability

Data sharing is not applicable to this protocol article as no datasets will be generated or analyzed.

Declarations

Ethics approval and consent to participate

The Scientific Ethics Committees for the Central Denmark Region reviewed the protocol and found the trial to be exempted from ethics approval (ref no. 1–10-72–124-22). The institutional ethics review board of Aarhus University approved the trial (ref. no. 2023–009). Informed consent will be obtained electronically through an online questionnaire.

Consent for publication

Not applicable—study protocol (no data generated).

Competing interests

The authors declare no competing interests.

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Received: 11 June 2025 Accepted: 24 September 2025

Published online: 12 December 2025

References

- GlobalData Plc. The Complexities of Physician Supply and Demand: Projections From 2021 to 2036. Washington, DC: AAMC; 2024.

- Wu L, Liu S, Lommen J, Pudwell J, Pelland L, Bougie O. Prevalence of musculoskeletal pain among gynecologic surgeons performing laparoscopic procedures: a systematic review and meta-analysis. *Int J Gynaecol Obstet*. 2023;161(1):151–8.
- Gabrielson AT, Tanidir Y, Castellani D, Ragoori D, Jean LE, Corrales M, et al. A global survey of ergonomics practice patterns and rates of musculoskeletal pain among urologists performing retrograde intrarenal surgery. *J Endourol*. 2022;36(9):1168–76. <https://doi.org/10.1089/end.2022.0075>.
- Young RJ, Allen A, McIntire D, Robinson EF, Bougie O, Kho KA. Work related pain in gynecologic surgeons - a national survey. *J Minim Invasive Gynecol*. 2025. <https://doi.org/10.1016/j.jmig.2025.01.014>.
- Dixon F, Vitish-Sharma P, Khanna A, Keeler BD. Work-related musculoskeletal pain and discomfort in laparoscopic surgeons: an international multispecialty survey. *Ann R Coll Surg Engl*. 2023;105(8):734–8.
- Gutierrez-Diez MC, Benito-Gonzalez MA, Sancierian R, Gandarillas-Gonzalez MA, Redondo-Figuero C, Manuel-Palazuelos JC. A study of the prevalence of musculoskeletal disorders in surgeons performing minimally invasive surgery. *Int J Occup Saf Ergon*. 2018;24(1):111–7.
- Dalager T, Søgaard K, Boyle E, Jensen PT, Mogensen O. Surgery is physically demanding and associated with multisite musculoskeletal pain: a cross-sectional study. *J Surg Res*. 2019;240:30–9.
- Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of work-related musculoskeletal disorders among surgeons and interventionalists: a systematic review and meta-analysis. *JAMA Surg*. 2018;153(2):e174947-e.
- Seagull FJ. Disparities between industrial and surgical ergonomics. *Work*. 2012;41(Suppl 1):4669–72.
- de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Luxembourg: European Agency for Safety and Health at Work; 2019.
- Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg*. 2010;210(3):306–13.
- Liang B, Qi L, Yang J, Cao Z, Zu X, Liu L, et al. Ergonomic status of laparoscopic urologic surgery: survey results from 241 urologic surgeons in China. *PLoS ONE*. 2013;8(7):e70423-e.
- Wauben LSG, Van Veelen MA, Gossot D, Goossens RHM. Application of ergonomic guidelines during minimally invasive surgery: a questionnaire survey of 284 surgeons. *Surg Endosc Other Interv Tech*. 2006;20(8):1268–74.
- Franasiak J, Ko E, Kidd J, Alvarez-Secord A, Bell M, Boggess J, et al. Physical strain and urgent need for ergonomic training among gynecologic oncologists who perform minimally invasive surgery. *Gynecol Oncol*. 2012;125(2):S190-S.
- Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics workshop improves musculoskeletal symptoms in general surgery residents. *J Surg Res*. 2022(k7b, 0376340).
- Pierce SM, Heiman AJ, Ricci JA. Evaluating the current state of ergonomics education offered to students in US medical students. *Am Surg*. 2023;89(5):1798–1806. <https://doi.org/10.1177/00031348211063555>.
- Epstein S, Tran BN, Capone AC, Ruan QZ, Fukudome EY, Ricci JA, et al. The current state of surgical ergonomics education in U.S. surgical training: a survey study. *Ann Surg*. 2019;269(4):778–84.
- Cavanagh J, Brake M, Kearns D, Hong P. Work environment discomfort and injury: an ergonomic survey study of the American Society of Pediatric Otolaryngology members. *Am J Otolaryngol*. 2012;33(4):441–6.
- Sweeney K, Mackey M, Spurway J, Clarke J, Ginn K. The effectiveness of ergonomics interventions in reducing upper limb work-related musculoskeletal pain and dysfunction in sonographers, surgeons and dentists: a systematic review. *Ergonomics*. 2021;64(1):1–38.
- Sjøgaard G, Christensen JR, Justesen JB, Murray M, Dalager T, Fredslund GH, et al. Exercise is more than medicine: the working age population's well-being and productivity. (2213–2961 (Electronic)).
- Sundstrup E, Seeberg KGV, Bengtsen E, Andersen LL. A systematic review of workplace interventions to rehabilitate musculoskeletal disorders among employees with physically demanding work. *J Occup Rehabil*. 2020;30(4):588–612. <https://doi.org/10.1007/s10926-020-09879-x>.
- Sjøgaard G, Mann S, Jensen JSD, Oestergaard AS, Dalager T. The elixir of muscle activity and kinesiology in a health perspective: evidence of worksite tailored exercise training alleviating muscle disorders. *J Electromyogr Kinesiol*. 2021;61(September).

23. Lloyd GL, Chung ASJ, Steinberg S, Sawyer M, Williams DH, Overbey D. Is your career hurting you? The ergonomic consequences of surgery in 701 urologists worldwide. *J Endourol*. 2019;33(12):1037–1042. <https://doi.org/10.1089/end.2019.0150>.
24. Sjøgaard G, Justesen JB, Murray M, Murray M, Dalager T, Dalager T, Sjøgaard K, Sjøgaard K. A conceptual model for worksite intelligent physical exercise training—IPET—intervention for decreasing life style health risk indicators among employees: a randomized controlled trial. 2014(1471–2458 (Electronic)).
25. Chan A-W, Boutron I, Hopewell S, Moher D, Schulz KF, Collins GS, et al. SPIRIT 2025 statement: updated guideline for protocols of randomised trials. *PLoS Med*. 2025;22(4):e1004589. <https://doi.org/10.1371/journal.pmed.1004589>.
26. Hoffmann TC, Glasziou PP, Boutron I, Milne R, Perera R, Moher D, et al. Better reporting of interventions: Template for Intervention Description and Replication (TIDieR) checklist and guide. *BMJ*. 2014;348:g1687. <https://doi.org/10.1136/bmj.g1687>.
27. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: a review of surgical ergonomics literature and development of educational illustrations. *Am J Surg*. 2024;235:115551. <https://doi.org/10.1016/j.amjsurg.2023.11.005>.
28. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: a multi-center cohort study. *Appl Ergon*. 2017;60:334–41.
29. Dorion D, Darveau S. Do microbreaks prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. *Ann Surg*. 2013;257(2):256–9.
30. Engelmann C, Schneider M, Kirschbaum C, Grote G, Dingemann J, Schoof S, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: a randomized clinical trial. *Surg Endosc*. 2011;25(4):1245–50.
31. Mayo_Clinic. OR Stretch: Mayo Clinic; [updated 2024]. Available from: www.OrStretch.Mayoclinic.org.
32. Abdelall ES, Lowndes BR, Abdelrahman AM, Hawthorne HJ, Hallbeck MS. Mini breaks, many benefits: development and pilot testing of an intra-operative microbreak stretch web-application for surgeons. *Proc Hum Factors Ergon Soc Annu Meet*. 2018;62(1):1042–6.
33. Sjøgaard K, Sjøgaard G. Physical activity as cause and cure of muscular pain: evidence of underlying mechanisms. *Exerc Sport Sci Rev*. 2017;45(3):136–45.
34. Dalager T, Bredahl TG, Pedersen MT, Boyle E, Andersen LL, Sjøgaard G. Does training frequency and supervision affect compliance, performance and muscular health? A cluster randomized controlled trial. *Man Ther*. 2015;20(5):657–65.
35. Sjøgaard G, Sjøgaard K, Hansen AF, Ostergaard AS, Teljigovic S, Dalager T. Exercise prescription for the work-life population and beyond. *J Funct Morphol Kinesiol*. 2023;8(2):48. <https://doi.org/10.3390/jfmk8020073>.
36. Borg G, Hassmén P, Fau - Lagerström M, Lagerström M. Perceived exertion related to heart rate and blood lactate during arm and leg exercise. (0301–5548 (Print)).
37. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334–59.
38. Dalager T, Justesen JB, Murray M, Boyle E, Sjøgaard G. Implementing intelligent physical exercise training at the workplace: health effects among office workers—a randomized controlled trial. *Eur J Appl Physiol*. 2016;116(7):1433–42.
39. Lange B, Toft P, Myburgh C, Sjøgaard G. Effect of targeted strength, endurance, and coordination exercise on neck and shoulder pain among fighter pilots: a randomized-controlled trial. *Clin J Pain*. 2013;29(1):50–9.
40. Gram B, Holtermann A, Sjøgaard K, Sjøgaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers—a randomized controlled intervention study. *Scand J Work Environ Health*. 2012;38(5):467–75.
41. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon*. 1987;18(3):233–7.
42. Ware J, Jr., Kosinski M, Fairclough D, Keller SD, Keller SD. A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. (0025–7079 (Print)).
43. Creedy DK, Sidebotham M, Gamble J, Pallant J, Fenwick J. Prevalence of burnout, depression, anxiety and stress in Australian midwives: a cross-sectional survey. *BMC Pregnancy Childbirth*. 2017;17(1):13.
44. Kristensen TS, Borritz M, Villadsen E, Christensen KB. The Copenhagen Burnout Inventory: a new tool for the assessment of burnout. *Work Stress*. 2005;19(3):192–207. <https://doi.org/10.1080/02678370500297720>.
45. Tuomi K, IJ, Jankola A, Katajarinne L, Tulkki A. Work ability index: Tuomi, K. et al. Institute of Occupational Health, Helsinki, Finland, pp. 18 + 6. ISBN 951–802–029–9. Elsevier India Pvt Ltd; 1995. p. 71–2.
46. de Zwart BCH, Frings-Dresen MHW, van Duivenbooden JC. Test–retest reliability of the Work Ability Index questionnaire. *Occupational medicine (Oxford)*. 2002;52(4):177–81.
47. WHO guidelines on physical activity and sedentary behaviour. Geneva: World Health Organization; 2020.
48. Grimby G, Börjesson M, Jonsdottir IH, Schnohr P, Thelle DS, Saltin B. The “Saltin-Grimby Physical Activity Level Scale” and its application to health research. *Scand J Med Sci Sports*. 2015;25 Suppl 4:119–25. <https://doi.org/10.1111/sms.12611>.
49. Strøyer J, Essendrop M, Jensen LD, Warming S, Avlund K, Schibye B. Validity and reliability of self-assessed physical fitness using visual analogue scales. *Percept Mot Skills*. 2007;104(2):519–33. <https://doi.org/10.2466/pms.104.2.519-533>.
50. Ilmarinen J. The Work Ability Index (WAI). *Occupational Medicine*. 2007;57(2):160.
51. Kaergaard A, Andersen JH, Rasmussen K, Mikkelsen S. Identification of neck-shoulder disorders in a 1 year follow-up study. Validation of a questionnaire-based method. *Pain*. 2000;86(3):305–10.
52. Olsen MF, Bjerre E, Hansen MD, Tendal B, Hilden J, Hrobjartsson A. Minimum clinically important differences in chronic pain vary considerably by baseline pain and methodological factors: systematic review of empirical studies. *J Clin Epidemiol*. 2018;101(87–106):e2.
53. Johnston V, Chen X, Welch A, Sjøgaard G, Comans TA, McStea M, et al. A cluster-randomized trial of workplace ergonomics and neck-specific exercise versus ergonomics and health promotion for office workers to manage neck pain—a secondary outcome analysis. *BMC Musculoskelet Disord*. 2021;22(1):68.
54. Andersen LL, Kjær M, Sjøgaard K, Hansen L, Kryger AI, Sjøgaard G. Effect of two contrasting types of physical exercise on chronic neck muscle pain. *Arthritis Rheum*. 2008;59(1):84–91.
55. Zebis MK, Andersen LL, Pedersen MT, Mortensen P, Andersen CH, Pedersen MM, et al. Implementation of neck/shoulder exercises for pain relief among industrial workers: a randomized controlled trial. *BMC Musculoskelet Disord*. 2011. <https://doi.org/10.1186/1471-2474-12-205>.
56. Broglio K. Randomization in clinical trials: permuted blocks and stratification. *JAMA*. 2018;319(21):2223–4.
57. Jarvinen TL, Sihvonen R, Bhandari M, Sprague S, Malmivaara A, Paavola M, et al. Blinded interpretation of study results can feasibly and effectively diminish interpretation bias. *J Clin Epidemiol*. 2014;67(7):769–72.
58. StataCorp. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC; 2021.
59. Davila VJ, Meltzer AJ, Hallbeck MS, Stone WM, Money SR. Physical discomfort, professional satisfaction, and burnout in vascular surgeons. *J Vasc Surg*. 2019;70(3):913–20.e2.
60. Norasi H, Kim J, Hallbeck MS, Cerri PE, Elli EF, Tollefson MK, et al. Surgeons' dominant surgical modality: impacts on wellbeing, burnout, and interventions for neuromusculoskeletal disorders. *Am J Surg*. 2024. <https://doi.org/10.1016/j.amjsurg.2024.05.010>.
61. Vijendren A, Yung M, Sanchez J, Duffield K. Occupational musculoskeletal pain amongst ENT surgeons—are we looking at the tip of an iceberg? *J Laryngol Otol*. 2016;130(5):490–6.
62. Dixon F, Vitish-Sharma P, Khanna A, Keeler B. An international multi-specialty survey of work-related musculoskeletal pain in laparoscopic surgeons. *Br J Surg*. 2023;110(Supplement 6):vi52.
63. Allespach H, Sussman M, Bolanos J, Atri E, Schulman CI. Practice longer and stronger: maximizing the physical well-being of surgical residents with targeted ergonomics training. *J Surg Educ*. 2020;77(5):1024–7.
64. Franasiak J, Craven R, Mosaly P, Gehrig PA. Feasibility and acceptance of a robotic surgery ergonomic training program. *JSLN Soc Laparoendosc Surg*. 2014;18(4):e2014.00166–e2014.

65. van Det MJ, Meijerink WJ, Hoff C, van Veelen MA, Pierie JP. Ergonomic assessment of neck posture in the minimally invasive surgery suite during laparoscopic cholecystectomy. *Surg Endosc.* 2008;22(11):2421–7.
66. van Veelen MA, Jakimowicz JJ, Goossens RHM, Meijer DW, Bussmann JBJ. Evaluation of the usability of two types of image display systems, during laparoscopy. *Surg Endosc.* 2002;16(4):674–8.
67. Hokenstad ED, Hallbeck MS, Lowndes BR, Morrow MM, Weaver AL, McGree M, et al. Ergonomic robotic console configuration in gynecologic surgery: an interventional study. *J Minim Invasive Gynecol.* 2021;28(4):850–9.
68. Kromberg LS, Kildebro NV, Mortensen LQ, Amirian I, Rosenberg J. Micro-breaks in laparoscopic appendectomy have no effect on surgeons' performance and well-being. *The Journal of surgical research.* 2020;251(k7b, 0376340):1–5.
69. Kawahira H, Nakamura R, Shimomura Y, Oshiro T, Okazumi S, Lefor AK. A wearable lower extremity support for laparoscopic surgeons: a pilot study. *Asian J Endosc Surg.* 2021;14(1):144–8.
70. Nishimoto W, Kawahira H, Shimomura Y, Nishizawa Y, Ito M. A standing posture support device that reduces laparoscopic surgeons' occupational lower limb stress. *Minim Invasive Ther Allied Technol.* 2019;28(3):151–6.
71. Giagio S, Volpe G, Pillastrini P, Gasparre G, Frizziero A, Squizzato F. A preventive program for work-related musculoskeletal disorders among surgeons: outcomes of a randomized controlled clinical trial. *Ann Surg.* 2019;270(6):969–75.
72. Van Eerd D, Munhall C, Irvin E, Rempel D, Brewer S, van der Beek AJ, et al. Effectiveness of workplace interventions in the prevention of upper extremity musculoskeletal disorders and symptoms: an update of the evidence. *Occup Environ Med.* 2016;73(1):62–70.
73. Rasmussen CDN, Holtermann A, Bay H, Søgaard K, Birk Jørgensen M. A multifaceted workplace intervention for low back pain in nurses' aides: a pragmatic stepped wedge cluster randomised controlled trial. *Pain.* 2015. <https://doi.org/10.1097/j.pain.0000000000000234>.
74. Thompson D, Rattu S, Tower J, Egerton T, Francis J, Merolli M. Mobile app use to support therapeutic exercise for musculoskeletal pain conditions may help improve pain intensity and self-reported physical function: a systematic review. *J Physiother.* 2023;69(1):23–34.
75. Christiansen HJ, Søgaard K, Justesen JB, Sjøgaard G, Dalager T. Long term cardiovascular health effects of intelligent physical exercise training among office workers—a 2 year follow up of a randomized controlled trial. *J Occup Environ Med.* 2023;65(10):813–9.
76. Dalager T, Højmark A, Jensen PT, Søgaard K, Andersen LN. Using an intervention mapping approach to develop prevention and rehabilitation strategies for musculoskeletal pain among surgeons. *BMC Public Health.* 2019;19(1):320.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

PAPER III – ERGO PAPER

Awareness, Practice, and Perceptions Among Abdominal and Pelvic Surgeons Following an Ergonomic Educational Initiative: A Cross-Sectional Study

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ABSTRACT

This study assessed surgeons' awareness and practice (uptake), and perceptions of the Good Ergonomics recommendations (ERGO) after a pragmatic launch, and examined whether uptake differed by musculoskeletal pain (MSP) frequency. Abdominal and pelvic surgeons from nine Danish hospital departments were introduced to ERGO, comprising ergonomic working postures in the operating room and microbreaks. Twelve weeks later, surgeons completed an online survey on uptake, perceptions and MSP. Of 313 eligible surgeons, 104 responded (33%). Awareness was high for both ergonomic working postures (93%) and microbreaks (90%). Practice differed by components: 85% of surgeons reported practicing ergonomic working postures most of the time or always, compared with 34% for microbreaks. MSP during surgery was common, which 74% report MSP at least sometimes. No clear associations were found between MSP frequency and ERGO uptake. Although perceptions were generally positive, consistent microbreak practice may require greater team support and additional training.

Keywords Surgical ergonomics, microbreaks, musculoskeletal pain

1 INTRODUCTION

Musculoskeletal pain (MSP) is highly prevalent among surgeons, including abdominal and pelvic surgeons (1-4). This may negatively affect surgeon wellbeing (5), increase the risk of burnout (6), and influence both surgical modality preference and surgical performance (7-13).

Surgeons are routinely exposed to intraoperative ergonomic risk factors, such as awkward and static postures, repetitive tasks, and limited opportunities for muscular rest, which increase the risk of MSP (14). In response, a growing body of surgical ergonomics literature and recommendations have emerged (15-20). Two recurring strategies in this literature are ergonomically sound working postures and intraoperative microbreaks. Working posture has received particular attention because prolonged static and awkward positioning represent key biomechanical exposures inherent to performing surgery (21, 22). Microbreaks have likewise been proposed as a feasible strategy (10, 23) to introduce brief periods of muscular recovery during prolonged procedures, with the aim to counteract muscular fatigue and MSP.

However, surgeons still report limited ergonomics knowledge (3, 4, 17, 21), and ergonomic education is rarely incorporated into medical school or residency curricula (24). This is important because greater ergonomic awareness has been associated with better ergonomic practice (25).

Nevertheless, the extent to which ergonomic recommendations are taken up in surgical practice remains unclear, particularly following a pragmatic ergonomic initiative in a Danish context. To address this, we developed the Good Ergonomics recommendations (ERGO) comprising two practice-oriented components: ergonomic working postures and microbreaks. These components were informed by a review of surgical ergonomic interventions (26), the broader ergonomics literature (15, 27, 28). The launch was intended as an educational initiative to establish a basic shared level of ergonomic awareness and practice.

The objective of this study was to assess awareness and practice (uptake) and perceptions of ERGO 12 weeks after launch. Further, we aimed to explore whether MSP frequency was associated with ERGO uptake.

The hypothesis is that surgeons who frequently experience MSP are more likely to optimize their ergonomics. Understanding the uptake of pragmatically launched ergonomic recommendations in routine surgical settings may inform future efforts to prevent surgeon MSP.

2 METHODS

2.1 Study design

This cross-sectional study used an online survey with convenience sampling and reports results from the completed ERGO phase (Fig. 1). ERGO was designed as an educational

initiative to establish a shared understanding of surgical ergonomic principles prior to a randomized controlled trial (RCT) in which ERGO serves as the standard care (29). The reporting follows the STROBE checklist for cross-sectional studies and the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) (30, 31).

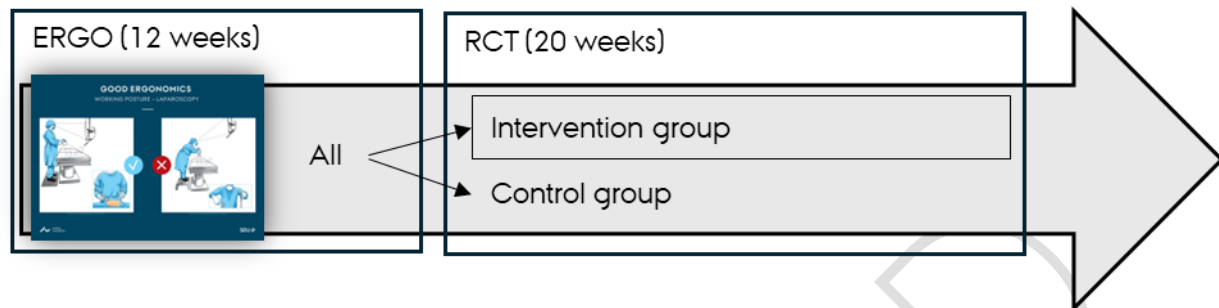


Figure 1 Overview of the ERGO educational phase (reported here), conducted prior to the randomized controlled trial (RCT) (29).

2.2 Setting and Participants

Between June 2023 and February 2025, 12 Danish regional and academic hospital departments were invited to participate in the ERGO initiative. The invited departments specialized in gynecology, urology, and colorectal surgery, in which conventional laparoscopic, robot-assisted surgery, open or mixed surgical practice were performed. Surgeons performing other modalities were also encouraged to apply the ERGO principles, although no modality-specific materials were developed for these procedures. Twelve weeks after the ERGO launch at each site, all surgeons in departments that agreed to participate were invited to complete the online survey, resulting in a convenience sample.

2.3 The ERGO recommendations

The ERGO recommendations were informed by a review of surgical ergonomic interventions (26) and the broader ergonomics literature (15, 27, 28). ERGO was designed as a pragmatic educational initiative with minimal economic and organizational demands, focusing on behavioral adjustments that could be adopted without additional equipment, formal training programs, or structural changes within participating departments. ERGO consisted of two key components: optimizing ergonomic working postures and performing intraoperative microbreaks. Optimized postures aim to reduce biomechanical load and sustained muscular strain (14), while microbreaks may allow short periods of variation in muscle activity that may help counteract fatigue associated with sustained static muscle activity (10, 23).

2.3.1 The ERGO launch

The ERGO launch used a pragmatic, low-resource approach designed to increase awareness of, and to enable voluntary practice of the ERGO components (Fig. 2). The ERGO launch activities were informed by the Behavior Change Wheel (BCW) which describes behavior as a product of three interacting components: capability, opportunity and motivation (COM-B). Provision of information was intended to target capability; opportunity through visual prompts and practical suggestions for behavior adoption; and motivation through

communicating the relevance and importance of surgical ergonomics for surgeon MSP, as well as habit formation. Together, these activities were intended to promote ergonomic behavior in surgical practice.

First, oral lectures were given. Shortly after lectures, posters of good surgical ergonomics were displayed in and around the operating rooms (OR) which featured QR codes linking to two short informational videos covering the rationale for and the importance of ergonomic working postures and microbreaks, respectively. The surgeons were encouraged to take the lead in adopting the initiative, with an emphasis on well-being of the entire OR team to foster a supportive environment and to promote team-wide ergonomic awareness (14, 15). In five (of the 9) departments, surgeons requested OR nurses also be briefed about ERGO to support shared understanding and facilitate microbreak practice. As the roll-out proceeded sequentially over two years, learning points from each site launch were informally evaluated and carried forward to subsequent launches.

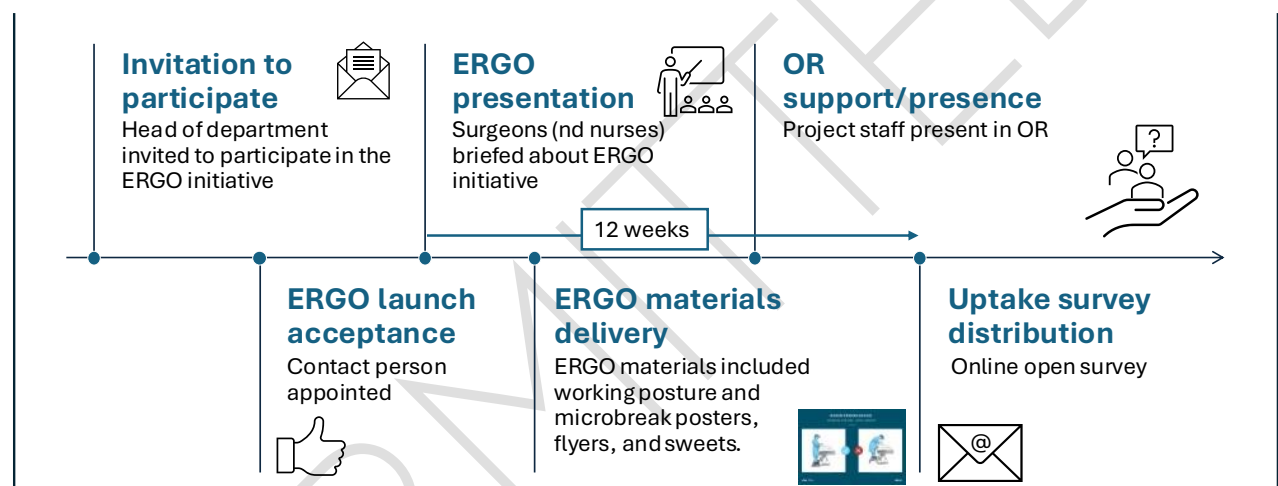


Figure 2 ERGO launch activities

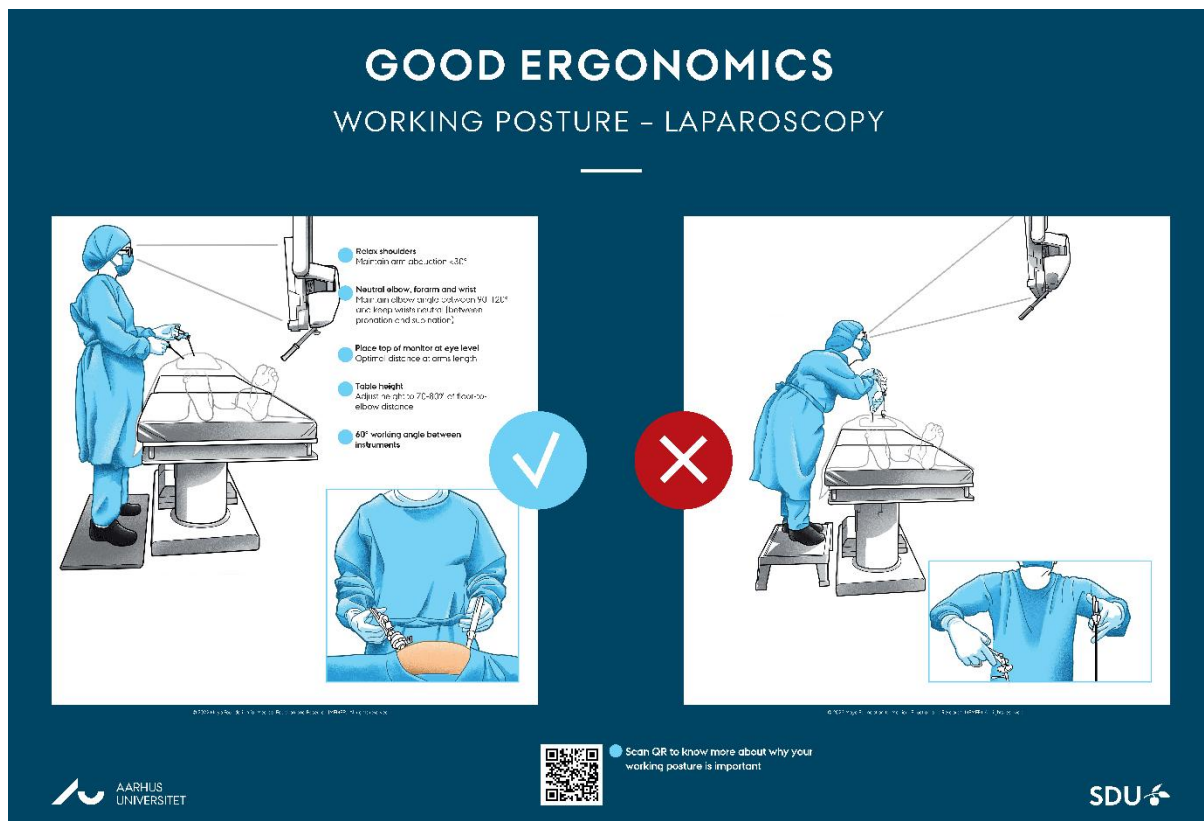


Figure 3 ERGO poster illustrating recommended working postures during laparoscopic surgery, including key ergonomic posture adjustments (Adapted from Tetteh et al. 2023 (32)).

2.3.2 Component 1: Ergonomic Working Postures

Ergonomic working postures were promoted using three modality-specific posters illustrating optimal body positioning and equipment adjustments to minimize muscular strain (32). Fig. 3 illustrates the poster for laparoscopic surgery with adjustment suggestions (blue dots) and QR code linking to a short video. The posters for open and robot-assisted surgery can be found in supplementary materials (eFigure 1 and 2). Surgeons were at the lectures encouraged to choose one adjustment initially and to implement it consistently before gradually incorporating additional changes into routine OR practice based on the principles of habit-formation (33).

2.3.3 Component 2: Microbreaks

The other component, microbreaks, aimed at inducing variation in muscle activation and rest for those muscle fibers highly active. The microbreaks consisted of 90-second intentional breaks with guided stretching exercises during or immediately after surgery, locally adapted from Mayo Clinic's OR Stretch app (34) into a poster. At the time-out meeting, surgeons and nurses were encouraged to coordinate the facilitation of regular microbreaks, approximately every hour, either at defined surgical stages or by using a timer. Stretching instructions were provided via a) audio accessed via QR code, b) read aloud from the microbreak poster, or c) guided by memory. Fig. 4 illustrates the microbreak poster.

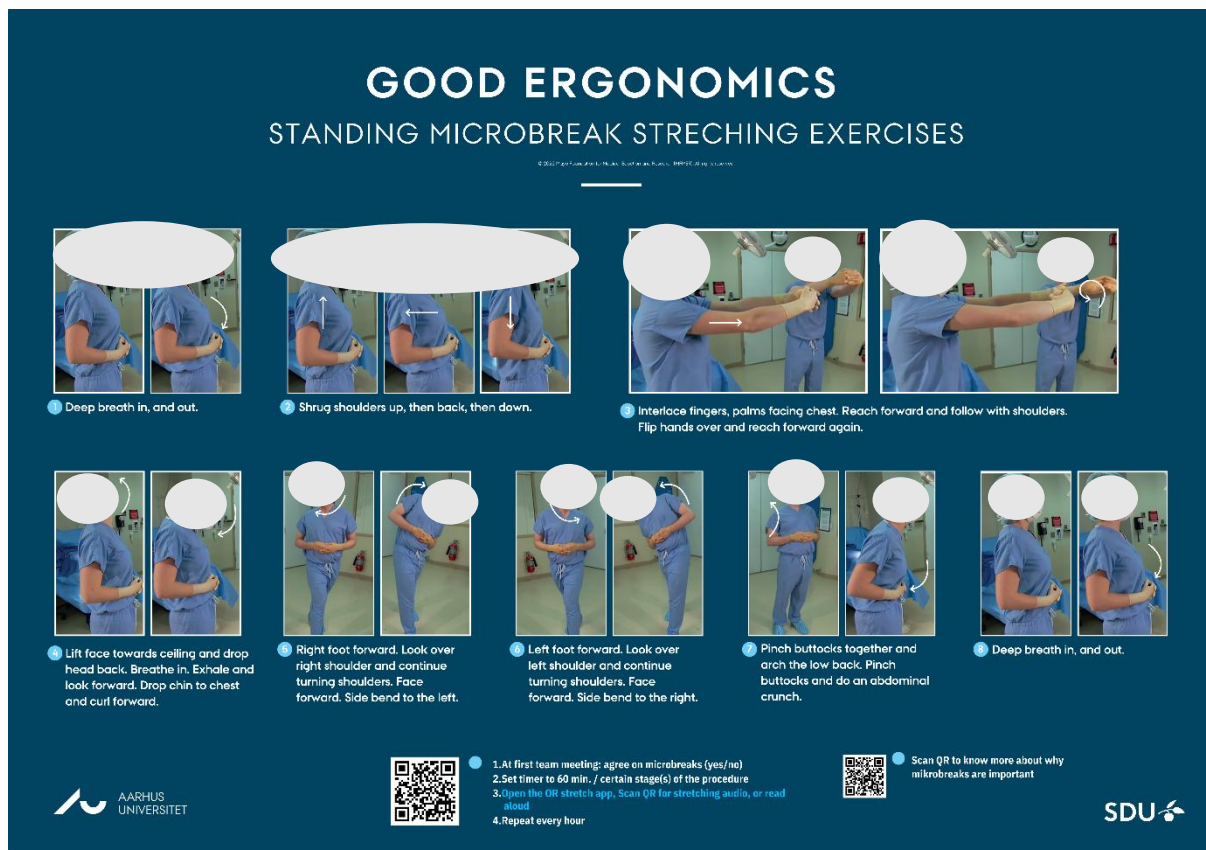


Figure 4 Microbreak poster with illustrations and written stretching instructions, and a QR code to scan for audio instructions.

Adherence to the recommendations was voluntary and not monitored. The launch of ERGO was cost-neutral for the participating departments, requiring only time for the presentation and the surgeons' effort to practice the ERGO components.

2.4 The Survey

2.4.1 Survey Administration

Twelve weeks following the launch of ERGO (Fig. 2), an open online survey link was distributed via e-mail from a local representative (surgeon or secretary) to all surgeons at participating departments. Reminders were sent 7 and 14 days after the initial invitation, and no incentives were offered. The survey was administered between December 2023 and October 2025 using REDCap (Research Electronic Data Capture, (35, 36)).

2.4.2 Survey Design and Content

The survey was developed to assess surgeons' work characteristics, awareness, practice and perceptions of the ERGO components, and frequency and location of MSP.

The survey design was guided by the BCW (37, 38) and the COM-B elements. The primary behavior of interest was self-reported practice of ERGO, assessed by asking "To what extent have you positioned yourself or the equipment in the OR to achieve an ergonomic working posture within the past three months?" or "To what extent have you taken one or more intra-operative microbreaks with stretching during the past three months?"

Since no validated surgeon-specific questionnaires exist to assess ERGO uptake and related characteristics, most items were purpose-designed. Items assessing MSP were adapted from the Nordic Musculoskeletal Questionnaire (NMQ) (39). An overview of the survey including response categories, collapsed responses etc., is provided in the appendix (Table A). Content validity was supported by surgeon input, who also pilot tested the survey to ensure clarity and usability.

The questionnaire was administered as an online survey using REDCap approximately 12 weeks after ERGO was launched. It was designed to take approximately 10-15 minutes to complete. It consisted of 19 core items including adaptive questioning used to tailor follow-up items based on prior responses (34 items in total). All core items were mandatory and included a “don’t know” response option. Respondents had the option of going back to review answers, and if left incomplete, the participants had the option of using a return code to come back later to continue where they left off.

2.4.3 Ethics, Data Protection, and Data Quality

The study was approved by the institutional review board at Aarhus University (2023-0563092). The survey introduction informed participants that completion was voluntary, that personal data would be collected, and that additional study information was accessible via a link. Completion and submission of the survey were considered to indicate implied consent. Data were stored in REDCap with password-restricted access limited to key study personnel. Duplicate entries were identified through manual checks for identical e-mail addresses, and in such cases, the first or most complete entry was retained. Partially completed surveys were included in the analysis if they contained a completed e-mail field.

2.5 Statistical analysis

No target sample size was specified in advance; the sample therefore comprised all surgeons who responded within the study timeframe. Descriptive statistics were used to summarize the categorical survey response options, and results are presented as numbers and percentages. Associations between MSP frequency and awareness and practice of the ERGO components were analyzed using an ordinal logistic regression. For these analyses, MSP frequency response options were collapsed into a three-category ordinal variable comprising never/rarely, sometimes, and most of the time/always. The proportional odds assumption was evaluated using a Wald test.

A two-sided p-value <0.05 was considered statistically significant. All analyses were performed using Stata version 17 or newer (StataCorp, College Station, TX, USA).

3 RESULTS

Twelve departments were invited to participate in the ERGO initiative, of which nine academic and regional hospital departments across five hospitals in Denmark accepted. ERGO was launched sequentially across five regional and academic hospitals in Denmark

between October 2023 to October 2025. were primary and assisting surgeons from nine hospital departments

The survey was distributed to 313 potentially eligible participants. Of those, a total of 104 surgeons completed the survey (33%). All respondents reported having performed surgery within the past three months. Most reported performing laparoscopy (75%), with 36% performing robot-assisted surgery, and 78% performing open surgery; responses were not mutually exclusive, and 84 reported performing more than one surgical modality within the last 3 months. Of these, 46 reported two modalities, 35 reported three, and 3 reported four modalities. Twenty-nine (29%) were specialized in colorectal surgery, 25 (24%) in gynecology, and 30 (28%) in urology, and 20 (19%) did not report a specialty.

3.1 Awareness of ERGO

Table 1 presents surgeons' overall and component-specific awareness of ERGO, and their sources of awareness.

Table 1 Awareness of the ERGO components.

VARIABLE	RESPONSE CATEGORY	N (%)
Overall awareness of Good Ergonomics	Yes	100 (96%)
	No	4 (4%)
	Don't know / No response	0 (0%)
Source of awareness Multiple responses possible	Oral presentation	81 (78%)
	Posters in operating room / corridor	75 (72%)
	Posters in department	53 (51%)
	E-mails	32 (31%)
	Video	14 (13%)
	Other*	8 (8%)
Awareness of ergonomic working postures	Very good	11 (11%)
	Good	42 (40%)
	Some	44 (42%)
	Very little / None	7 (7%)
Awareness of intra-operative microbreaks	Very good	17 (16%)
	Good	36 (35%)
	Some	40 (38%)
	Very little	8 (8%)
	None	3 (3%)

*Of the eight respondents who selected "Other" as their source of awareness, four reported an oral presentation and four reported a colleague as the source.

3.2 Practice of ERGO

3.2.1 Ergonomic Working Postures

Table 2 presents overall practice of ergonomic working postures during the past three months, as well as the most frequently reported posture adjustments during laparoscopic, robot-assisted, and open surgery. In laparoscopy, adjusting monitor height and lowering shoulders were reported most frequently. In robot-assisted surgery, chair height adjustment and armrest use were most common, and in open surgery bed height adjustment and positioning close to the patient/operative field were reported most often.

Table 2 Self-reported practice of ergonomic working postures and most frequently reported posture adjustments by surgical modality, with percentage within each variable.

VARIABLE	RESPONSE CATEGORY	N (%)
Practice of ergonomic working postures (n= 104)	Always	22 (21%)
	Most of the time	67 (64%)
	Sometimes	8 (8%)
	Rarely	4 (4%)
	Never	1 (1%)
	Don't know	2 (2%)
Most frequently reported posture adjustments in laparoscopy (n= 78) Multiple responses possible	Adjust monitor height	66 (85%)
	Lowered shoulders	59 (76%)
	Adjust bed height	44 (56%)
	Neutral forearm	20 (26%)
	60 deg. Between instruments	20 (26%)
	Adjust monitor distance	19 (24%)
	Other	3 (4%)
Most frequently reported posture adjustments in robot assisted surgery (n= 37) Multiple responses possible	Adjust chair height	32 (86%)
	Use armrest	30 (81%)
	Other	26 (70%)
	Chair with back support	24 (65%)
	Upper body upright	23 (62%)
	Keeping feet on floor when not using foot pedal	17 (46%)
	30 deg. view ankle	3 (8%)
Most frequently reported posture adjustments in open surgery (n= 81) Multiple responses possible	Adjust bed height	79 (98%)
	Positioned close to patient/operative field	73 (90%)
	Neutral pelvis	31 (38%)
	Positioning foot pedal	31 (38%)
	Neutral neck	26 (32%)
	Neutral trunk	22 (27%)

	Other	2 (2%)
Barriers to consistent practice	More training	11 (85%)
Reported by surgeons with practice sometimes or less (n= 13)		
Multiple responses possible		
	More support from leaders	6 (46%)
	Other	4 (31%)
	More time to set up OR	3 (23%)
	More information	2 (15%)

Some of the surgeons reporting limited practice provided additional free-text comments. One respondent highlighted the need for a shared OR-team consensus on the importance of ergonomics and microbreaks, noting that a lack of consensus ends up affecting the youngest team members. Another respondent commented that the operating surgeon/attending surgeon should take the lead in incorporating ERGO practices in the OR. A third underscored the importance of developing good habits. One comment did not describe a barrier.

3.2.1.1 Perceptions of the Working Posture Component

Fig. 5 presents surgeons' perceptions of the working posture component. Seventy-six percent of the total sample (N= 104) agreed (partly agree, agree, strongly agree) that the posters illustrating ergonomic postures made it easier to work ergonomically in the OR, and 84% agreed that they pay attention to their working posture. Most respondents agreed that using ERGO is an effective way to prevent MSP (94%) and that everyone in the OR should be encouraged to follow the recommendations (95%). Fewer respondents agreed that the informational video (accessible via QR code) helped convey the importance of ergonomic postures and how they may prevent MSP (45%).

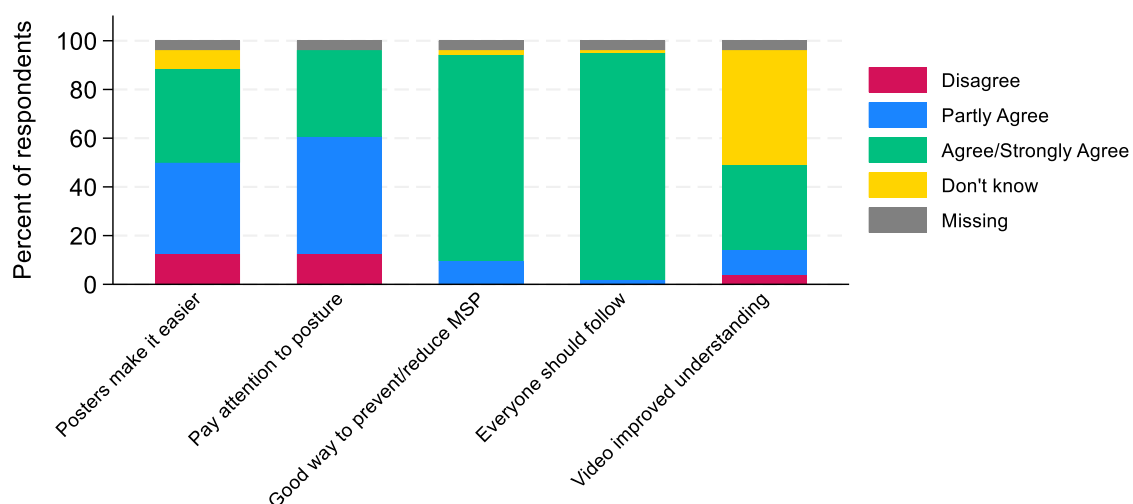


Figure 5 Percentage distribution of responses to statements on the working posture component. For each item, responses are categorized as disagree/strongly disagree, partly agree, agree/strongly agree, don't know, or missing, and displayed as stacked bars, summing to 100% per item.

3.2.2 Microbreaks

Table 3 presents self-reported microbreak frequency, prompts for initiation, and methods used to guide microbreak stretching exercises.

Table 3 Practice of microbreaks and related prompts and guidance methods, percentage within each variable.

VARIABLE	RESPONSE CATEGORY	N (%)
Practice of microbreaks (n= 104)	Always	4 (4%)
	Most of the time	31 (30%)
	Sometimes	27 (26%)
	Rarely	26 (25%)
	Never	12 (12%)
	Don't know	4 (4%)
	OR nurse	48 (77%)
What prompted the microbreak? Among those with practice at least sometimes (n= 62) Multiple responses possible	I remembered	39 (63%)
	Surgeon	18 (29%)
	Physical discomfort	13 (21%)
	Timer	5 (8%)
	Other	1 (2%)
	Read poster instructions	43 (69%)
	Memory	20 (32%)
How were the exercises guided? Among those with practice at least sometimes (n= 62) Multiple responses possible	Used QR code audio	18 (29%)
	Other*	7 (11%)
	Support from OR staff	37 (57%)
	Support from surgeons	27 (42%)
	Training	24 (37%)
	Other	21 (32%)
	Support from leaders	18 (28%)
Barriers to consistent practice Reported by surgeons with practice sometimes or less (n= 65) Multiple responses possible	Information	7 (11%)

*Other: Among the seven respondents who answered other to how exercises were guided, six commented that they did their own variations of the exercises.

Twenty-one respondents left free-text comments: Seven indicated short procedures/low perceived need for microbreaks, and six mentioned insufficient cueing (reminders/prompts) as the barrier. Four mentioned OR team and organizational barriers, and one mentioned time pressure, and three comments did not comment on barriers.

3.2.2.1 Perceptions of the Microbreak Component

Fig. 6 presents surgeons' perceptions of the microbreak component. Fifty-three percent of the total sample (N=104) agreed (partly agree/agree/strongly agree) that microbreaks are easy to remember, and 72% agreed that microbreaks are easy to incorporate into the surgical workflow. Most respondents agreed that microbreaks are an effective way to prevent MSP (81%), and that everyone in the operating room should be encouraged to take regular microbreaks (93%). Fewer respondents agreed that the short informational microbreak video improved their understanding of how to prevent MSP with microbreaks (43%).

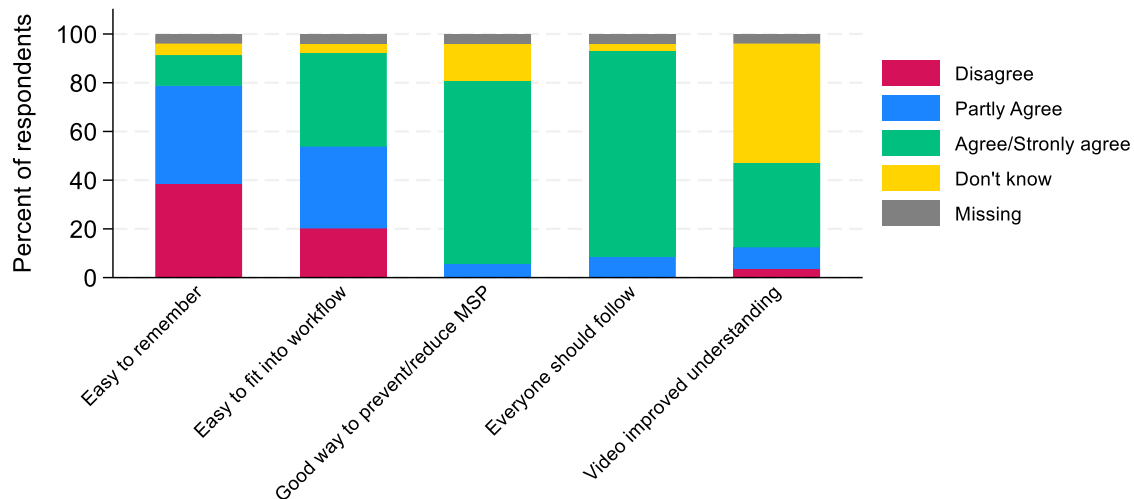


Figure 6 Percentage distribution of responses to statements on the microbreak component. For each item, responses are categorized as disagree/strongly disagree, partly agree, agree/strongly agree, don't know, or missing, and displayed as stacked bars, summing to 100% per item.

3.2.3 Musculoskeletal Pain – Prevalence, Characteristics and Associations

Table 4 presents frequency of MSP during surgery, affected body regions among surgeons reporting MSP at least sometimes, mitigating strategies and perceived consequences on choice of surgical modality.

Table 4 Frequency of musculoskeletal pain during surgery, affected body regions, and actions taken to reduce physical strain and choice of modality

VARIABLE	CATEGORY	N (%)
MSP during surgery in the past 3 months (n= 104)	Always	3 (3%)
	Most of the time	29 (28%)
	Sometimes	45 (43%)
	Rarely	20 (19%)
	Never	7 (7%)
	Don't know	0 (0%)
MSP by body regions	Neck	43 (41%)
Among those with MSP at least sometimes (n= 77)		
Multiple responses possible	Shoulders	39 (38%)

	Lower back	37 (36%)
	Upper back	31 (30%)
	Wrists/hands	22 (21%)
	Knees	7 (7%)
	Elbows	4 (4%)
	Hips	3 (3%)
	Ankles/feet	2 (2%)
Actions taken to reduce strain	Took microbreaks	46 (44%)
Among those with MSP at least sometimes (n= 77)		
Multiple responses possible		
	Changed position	37 (36%)
	Avoided surgical procedures	22 (21%)
	Pain medication	14 (13%)
	Other*	0 (0%)
MSP affected choice of surgical modality	Yes, most of the time	2 (2%)
Among those with MSP at least sometimes (n= 77)		
Multiple responses possible		
	Yes, a few times	2 (2%)
	No, never	70 (67%)
	Don't know	3 (3%)
	Blank	27 (26%)

*These included engaging in physical training outside of work, stretching or mobility work, manual treatment methods or a combination of the three, or using ergonomic OR set-ups, footwear or anti-fatigue mats.

Among the 77 surgeons reporting MSP at least sometimes, 61 (79%) reported MSP in two or more body regions (multi-site MSP). The two most common site combinations are neck and upper back 6 (10%), and neck, lower back, and shoulders 6 (10%).

3.2.3.1 MSP, Awareness and Practice

Table 5 presents the ordinal logistic regression results assessing the association between MSP frequency and awareness or practice of the two ERGO components. No statistically significant associations were observed between MSP frequency and awareness or practice of either component. However, the point estimates suggest divergent patterns across the two ergonomic components: for posture, awareness and practice were less related to MSP frequency, as the ORs were generally at or below 1, whereas microbreak awareness and practice demonstrated that surgeons experiencing MSP more frequently tended to report greater awareness and more consistent practice of microbreaks (ORs above 1). However, these estimates were imprecise and should therefore be interpreted cautiously. The proportional odds assumptions were met for all models; however, formal verification was not possible for the posture-practice model.

Furthermore, awareness and practice were positively correlated for both components, with surgeons reporting higher awareness also tending to report more consistent practice of ergonomic working posture (Kendall's $\tau_b = 0.39$, $p < 0.001$) and microbreaks (Kendall's $\tau_b = 0.55$, $p < 0.001$).

Table 5 Ordinal logistic regression of the associations between MSP frequency and awareness and practice of the ERGO components

Outcome	MSP frequency	OR	95% CI			p-value
Posture awareness	Sometimes vs. never/rarely	0.45	0.18	-	1.10	0.08
	Most of the time/always vs never/rarely	0.89	0.34	-	2.33	0.82
Posture practice	Sometimes vs. never/rarely	0.84	0.32	-	2.21	0.72
	Most of the time/always vs never/rarely	1.13	0.40	-	3.17	0.82
Microbreak awareness	Sometimes vs. never/rarely	1.32	0.54	-	3.22	0.54
	Most of the time/always vs never/rarely	1.96	0.75	-	5.13	0.17
Microbreak practice	Sometimes vs. never/rarely	1.66	0.69	-	3.95	0.26
	Most of the time/always vs never/rarely	2.42	0.95	-	6.15	0.06

4 DISCUSSION

The pragmatic launch of ERGO was followed by overall high awareness and generally positive perception of both components. Practice differed by component, with ergonomic working postures more frequently reported than microbreaks. The three most cited barriers for microbreaks were insufficient support from OR staff and from surgeon colleagues, and need for additional training in microbreaks.

MSP was frequently experienced by surgeons, with the neck, shoulders and lower back the most reported sites involved in multi-site MSP. The regression analysis provided no clear evidence of an association between MSP frequency and awareness nor practice of ERGO. Although we hypothesized that surgeons with more frequent MSP would be more likely to adopt ergonomic practices, this pattern was not clearly reflected in the data from this sample.

4.1.1 Awareness and Practice

To interpret the observed differences in uptake, we draw on the COM-B model. Following the ERGO launch, surgeons reported awareness of both components, but practice was more uneven.

4.1.1.1 Microbreaks

In COM-B terms, limited microbreak practice appeared to reflect barriers related primarily to social opportunity and psychological capability, whereas physical opportunity barriers seemed less prominent. Social opportunity barriers were particularly evident, with lack of support from OR staff and fellow surgeons emerging as the two most frequently reported barriers. Comments further suggested that junior status may act as a barrier to microbreak practice, possibly because initiating breaks may be harder without supportive team dynamics and endorsement from senior colleagues (40). Psychological capability barriers were indicated by the proportion of surgeons reporting a need for more training to take microbreaks consistently. Related comments requesting additional external assistance such as a timer or alarm, or an embedded workflow prompt, suggest that consistent practice may depend not only on knowledge, but also on cues that support the behavior in routine practice.

Short procedures were described as a context in which microbreaks may pose a physical opportunity barrier, as the perceived need is lower. In contrast, most surgeons agreed that microbreaks are easy to fit into workflow, consistent with prior work (10). This apparent difference between overall perceived feasibility and context-specific barriers may reflect variation in procedure duration and workflow across the types of surgery performed in the included departments.

Reflective motivation for microbreaks was generally high, except during short procedures, with participants generally regarding microbreaks as beneficial for preventing MSP and that microbreaks should be adopted by the entire OR team. The contrast between positive perceptions and the limited consistent microbreak practice suggests that reflective motivation alone was insufficient to support routine uptake (41), and that a stronger implementation strategy may be needed, perhaps only targeting procedures exceeding one hour. The positive perceptions of microbreak incorporation have been reported elsewhere in the literature and are consistent with the present findings (10, 42, 43).

4.1.1.2 Posture adjustments

Consistent practice of ergonomic postures was generally high, and therefore barriers were reported by relatively few surgeons. Among those, insufficient training was the most frequently reported, suggesting a psychological capability barrier. Leadership support was the second most frequently reported barrier, indicating that social opportunity may also play a role, although less prominently than for microbreaks. Comments further suggested that junior status was also seen as a barrier for workstation adjustment, again indicating that senior endorsement may also be important for uptake.

In contrast to microbreaks, surgeons can adjust their posture more independently, requiring less coordination with the OR team, which may explain why social opportunity barriers appeared less relevant for this component. Nevertheless, a few respondents expressed a need for greater shared consensus on the importance of ergonomics in the OR, indicating that social opportunity, in the form of collective endorsement, may still be important for sustaining routine practice.

Reflective motivation to practice ergonomic work postures was also high, as reflected in the high perceived value of this ERGO component. This pattern is consistent with other studies of pragmatically delivered ergonomics training (8, 10, 42-45).

4.1.1.3 Implications for implementation

ERGO was designed as an ergonomic initiative to create awareness of its two components and encourage their uptake in routine surgical practice without requiring new equipment or major organizational change. Its pragmatic approach aimed to ensure that ergonomic education was scalable and feasible across diverse surgical settings.

In COM-B terms, the ERGO launch appears to have increased psychological capability (awareness), but changes in behavior, particularly regular microbreak practice, likely require stronger social opportunity through greater OR team and leadership support, along with further support for capability (13). One practical approach may be to embed microbreaks within existing OR routines, such as a pre-procedure ergonomics time-out checklist (46, 47),

where incorporation of microbreaks would be a natural addition. This may be particularly relevant in a hierarchical OR setting, where speaking up as a junior can be difficult if the senior resident or attending surgeon does not actively support ergonomic practices and microbreaks (42, 43, 48). More broadly, translating positive perceptions about ERGO into routine action will likely require support for behavior change such as creating new habits, which may be difficult if the social environment is a barrier (41). In the same literature, the presence of training and knowledge, active participation, and managerial/peer support are repeatedly identified as facilitating factors for successful implementation (41, 43, 49).

In our data, the key source of awareness of ERGO was the oral presentation at morning meetings. However, with the varying schedules and high turnover among staff (students/residents), ergonomic knowledge and skills must be conveyed repeatedly over time through mechanisms that do not rely on a single one-off introduction. We tried to account for this in the provision of short informational videos; however, they were not perceived as a good way to convey ERGO information. Accordingly, department leaders and senior surgeons may benefit from embedding ergonomic training and onboarding more systematically within the department's management systems (e.g., routine tasks, recurring brief refreshers, and standardized prompts) (41), and in academic settings, having regular ergonomics training modules for trainees (residents/fellows).

4.1.2 MSP prevalence, characteristics and associations

Among surgeons with MSP at least sometimes (74%), multi-site MSP was common (79%). This proportion, and the most frequently reported body-region combinations, are broadly comparable to findings reported in similar surgical populations in the literature (50).

The results provided no clear evidence of an association between MSP frequency and the awareness or practice of ERGO components. Although point estimates suggested lower posture awareness and practice, and higher microbreak awareness and practice among surgeons with MSP at least sometimes, the strongest association was observed for microbreak practice among surgeons reporting MSP most of the time or always compared to never or rarely (OR = 2.42, 95% CI: 0.95 – 6.15, $p=0.06$). Nevertheless, confidence intervals were wide across all estimates, indicating substantial uncertainty. Consequently, these analyses may have been underpowered, and a Type II error cannot be excluded. Several mechanisms may contribute to the observed patterns. First, reverse causation is plausible, whereby insufficient ergonomic awareness and practice contribute to frequent MSP, rather than MSP motivating subsequent ergonomic behavior as indicated by the present findings. Second, surgeons experiencing MSP may increase microbreak practice as a coping response, while microbreaks may also serve a preventive function by interrupting prolonged periods of low-intensity muscle activity (static) and allow the low-force muscle fibers that are overly active to recover (10, 51-53). These opposing mechanisms could obscure cross-sectional associations in either direction. Third, high workload or surgical case complexity or duration may simultaneously increase MSP risk (54, 55), and reduce the perceived or actual opportunity to adopt ergonomic practices (56) - a barrier also noted by participants in the present study and documented in the implementation literature (41).

From an organizational or institutional perspective, scalable ergonomics training that can be delivered with minimal resources appears to be feasible (8, 43, 44) and could be integrated into residency curricula and departmental onboarding as a first step in forming ergonomic awareness. However, initiatives like ERGO are unlikely to be sufficient as a standalone strategy for MSP prevention and management in this population and should be accompanied by additional preventive and rehabilitative approaches (57, 58), such as physical conditioning, namely tailored physical exercise training (59).

4.2 Limitations

This study has several limitations. First, the cross-sectional design limits inference about change over time and prevents causal conclusions. We did not record baseline awareness or practice of ergonomic behavior; therefore, we cannot determine whether the reported high awareness of ergonomic working postures reflects the ERGO launch or pre-existing knowledge. Reverse causation cannot be ruled out, as ergonomic awareness, practice and MSP may influence each other.

Second, measures were self-reported, which may not reflect actual behavior (over- or under-reporting). As in many other studies in this population (1-3, 7), the relatively low response rate may increase the risk of selection (non-response) bias, and self-reported survey data may be affected by recall and social desirability bias. If surgeons with particular interest in ergonomics or MSP were more likely to respond, uptake and MSP prevalence may be overestimated. Further, no validated questionnaire existed for several of our questions of interest.

Since this study is a pre-trial phase for an RCT (29), we did not collect sociodemographic characteristics which could have been relevant to account for, thus we did not adjust for possible confounding factors (e.g., sex, differences in surgical modality, years of experience, workload). Consequently, residual confounding may partly explain observed patterns in awareness and practice and their associations with MSP.

Across five departments, research staff were present in the ORs in the initial period to support the uptake of ERGO. With their presence the research staff answered questions, helped OR teams identify when it would be a good time to take a microbreak, and helped surgeons set up the OR as ergonomically as possible. Other aspects of support also varied since OR nurses were not uniformly briefed in all departments. Due to resource limitations and local preferences, research staff presence was limited to five departments. This resulted in variation in the launch support across sites, which may have influenced uptake, particularly for microbreaks since the OR nurses were the most frequently reported prompt for microbreaks. However, as the project progressed, new departments were more willing to appoint local ambassadors, and the learning from the first two sites enabled clearer communication about the scope of participation. Thus, although the first participating departments had research staff present, departments may also have differed in readiness and motivation for participation, which could introduce department-level selection and limit comparability across participating sites.

5 CONCLUSION

ERGO recommendations with two key components - ergonomic working postures and microbreaks - was pragmatically launched across nine Danish abdominal and pelvic surgical departments. After 12 weeks, surgeons reported high awareness of both components, but practice varied, with postural adjustments more frequently practiced than microbreaks. There was no clear evidence of an association between MSP frequency and awareness or practice of the two components. Overall, higher awareness was associated with more frequent practice. Overall perception of ERGO was positive, but consistent microbreak practice may require increased OR team support and additional skills training. These findings suggest that future implementation support may differ for individual behaviors (posture adjustments) vs. team-dependent behaviors (microbreaks).

6 ACKNOWLEDGEMENTS

In memoriam: Professor Pernille Tine Jensen (1964-2026) whose early contributions to this study are gratefully acknowledged.

7 DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION PROCESS.

During the preparation of this work the author(s) used ChatGPT (OpenAI) in order to improve grammar, readability, and overall clarity. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

8 CREDIT AUTHOR STATEMENT

Helle J. Christiansen: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Project administration. Susan Hallbeck: Methodology, Writing - Review & Editing. Chrouser: Methodology, Writing - Review & Editing. Ole Mogensen: Conceptualization, Writing - Review & Editing, Funding acquisition. Tina Dalager: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Funding acquisition.

9 FUNDING SOURCE

This work was supported by The Working Environment Research Fund (grant number 20215100734) and Aarhus University. The funders had no role in any aspect of the study or in the decision to submit the manuscript for publication.

10 DATA SHARING STATEMENT

Due to applicable data protection and privacy regulations, including the GDPR, the data supporting the findings of this study cannot be made publicly available. Access to de-identified data may be considered on reasonable request and with permission from the relevant institutional authorities.

11 REFERENCES

1. Alleblas CCJ, de Man AM, van den Haak L, Vierhout ME, Jansen FW, Nieboer TE. Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive Surgery: A Systematic Review. *Ann Surg*. 2017;266(6):905-20.
2. Wu L, Liu S, Lommen J, Pudwell J, Pelland L, Bougie O. Prevalence of musculoskeletal pain among gynecologic surgeons performing laparoscopic procedures: A systematic review and meta-analysis. *International Journal of Gynecology and Obstetrics*. 2023;161(1):151-8.
3. Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of Work-Related Musculoskeletal Disorders Among Surgeons and Interventionalists: A Systematic Review and Meta-analysis. *JAMA Surg*. 2018;153(2):e174947.
4. El Boghdady M, Ewalds-Kvist BM. General surgeons' occupational musculoskeletal injuries: A systematic review. (1479-666X (Print)).
5. Dalager T, Sogaard K, Bech KT, Mogensen O, Jensen PT. Musculoskeletal pain among surgeons performing minimally invasive surgery: a systematic review. *Surgical endoscopy*. 2017;31(2):516-26.
6. Keller DS, Narula N, Schwarz E, Mellinger JD, Feldman LS, Dort J, et al. A cross sectional survey on burnout and career satisfaction in surgeons: a joint work from the SAGES quality, outcomes, and safety and reimaging the practice of surgery burnout task forces. *Surg Endosc*. 2024;38(9):4776-87.
7. Stucky CH, Cromwell KD, Voss RK, Chiang YJ, Woodman K, Lee JE, et al. Surgeon symptoms, strain, and selections: Systematic review and meta-analysis of surgical ergonomics. *Ann Med Surg (Lond)*. 2018;27:1-8.
8. Allespach H, Sussman M, Bolanos J, Atri E, Schulman CI. Practice Longer and Stronger: Maximizing the Physical Well-Being of Surgical Residents with Targeted Ergonomics Training. *J Surg Educ*. 2020;77(5):1024-7.
9. Adams SR, Hacker MR, McKinney JL, Elkadry EA, Rosenblatt PL. Musculoskeletal Pain in Gynecologic Surgeons. *J Minim Invasive Gynecol*. 2013;20(5):656-60.
10. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Appl Ergon*. 2017;60:334-41.
11. Davis WT, Fletcher SA, Guillaumondegui OD. Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. *J Surg Res*. 2014;189(2):207-12 e6.
12. Ruitenburg MM, Frings-Dresen MH, Sluiter JK. Physical job demands and related health complaints among surgeons. *Int Arch Occup Environ Health*. 2013;86(3):271-9.
13. Chrouser K, Kim FJ, Smith A, Stoffel JT, Goldenberg M. Optimizing Outcomes in Urologic Surgery: Intraoperative Environmental, Behavioral, and Performance Considerations. *Urology Practice*. 2020;7(5):405-12.
14. Sogaard K, Sjogaard G. Physical Activity as Cause and Cure of Muscular Pain: Evidence of Underlying Mechanisms. *Exerc Sport Sci Rev*. 2017;45(3):136-45.
15. SURGEONS ACO. Surgical Ergonomics Recommendations. COMMITTEE ESE; 2022.
16. Gabrielson AT, Clifton MM, Pavlovich CP, Biles MJ, Huang M, Agnew J, et al. Surgical ergonomics for urologists: a practical guide. *Nature reviews Urology*. 2021;18(3):160-9.
17. Schluskel AT, Maykel JA. Ergonomics and Musculoskeletal Health of the Surgeon. *Clinics in colon and rectal surgery*. 2019;32(6):424-34.
18. Cardenas-Trowers O, Kjellsson K, Hatch K. Ergonomics: making the OR a comfortable place. *International urogynecology journal*. 2018;29(7):1065-6.

19. Lin E, Young R, Shields J, Smith K, Chao L. Growing pains: strategies for improving ergonomics in minimally invasive gynecologic surgery. *Current opinion in obstetrics & gynecology*. 2023;35(4):361-7.
20. Balafoutas D, Joukhadar R, Vlahos N. Optimising ergonomics in minimally invasive gynaecological surgery: a comprehensive review and practice recommendations. *Facts, views & vision in obgyn*. 2025;17(2):180-91.
21. Barrios EL, Polcz VE, Hensley SE, Sarosi GA, Mohr AM, Loftus TJ, et al. A narrative review of ergonomic problems, principles, and potential solutions in surgical operations. *Surgery (United States)*. 2023;174(2):214-21.
22. Dalager T, Jensen PT, Eriksen JR, Jakobsen HL, Mogensen O, Sogaard K. Surgeons' posture and muscle strain during laparoscopic and robotic surgery. *British Journal of Surgery*. 2020;107(6):756-66.
23. Park AE, Zahiri HR, Hallbeck MS, Augenstein V, Sutton E, Yu D, et al. Intraoperative "Micro Breaks" With Targeted Stretching Enhance Surgeon Physical Function and Mental Focus: A Multicenter Cohort Study. *Ann Surg*. 2017;265(2):340-6.
24. Pierce SM, Heiman AJ, Ricci JA. Evaluating the Current State of Ergonomics Education Offered to Students in US Medical Students. *Am Surg*. 2023;89(5):1798-806.
25. Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg*. 2010;210(3):306-13.
26. H. J. Christiansen HN, E. Tetteh, M. S. Hallbeck, K. Chrouser, O. Mogensen, P. T. Jensen, T. Dalager. Operating Room Ergonomics: Systematic Review of Musculoskeletal Health Outcomes in Abdominal and Pelvic Surgeons. Under review. 2026.
27. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: A review of surgical ergonomics literature and development of educational illustrations. *Am J Surg*. 2023.
28. National Institute for Occupational Safety and Health (NIOSH). Ergonomics and Musculoskeletal Disorders [Web page]. [Available from: <https://www.cdc.gov/niosh/ergonomics/index.html>].
29. Christiansen HJ, Sandal LF, Mogensen O, Norasi H, Chrouser K, Hallbeck MS, et al. Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA). *Trials*. 2025;26(1):565.
30. Vandembroucke JP, von Elm E, Altman DG, Gotzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. *PLoS Med*. 2007;4(10):e297.
31. Eysenbach G. Improving the quality of Web surveys: the Checklist for Reporting Results of Internet E-Surveys (CHERRIES). *J Med Internet Res*. 2004;6(3):e34.
32. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: A review of surgical ergonomics literature and development of educational illustrations. *Am J Surg*. 2024;235:115551.
33. Lally P, van Jaarsveld CHM, Potts HWW, Wardle J. How are habits formed: Modelling habit formation in the real world. *Eur J Soc Psychol*. 2010;40(6):998-1009.
34. Coleman Wood KA, Lowndes BR, Buus RJ, Hallbeck MS. Evidence-based intraoperative microbreak activities for reducing musculoskeletal injuries in the operating room. *Work (Reading, Mass)*. 2018;60(4):649-59.
35. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, et al. The REDCap consortium: Building an international community of software platform partners. *J Biomed Inform*. 2019;95:103208.

36. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform.* 2009;42(2):377-81.
37. Michie S, Atkins L, West R. *The Behaviour Change Wheel: A Guide to Designing Interventions*: Silverback Publishing; 2014.
38. Michie S, van Stralen MM, West R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Sci.* 2011;6(1):42-.
39. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied ergonomics.* 1987;18(3):233-7.
40. Tørring B, Gittell JH, Laursen M, Rasmussen BS, Sørensen EE. Communication and relationship dynamics in surgical teams in the operating room: an ethnographic study. *BMC Health Services Research.* 2019;19(1):528.
41. Yazdani A, Wells R. Barriers for implementation of successful change to prevent musculoskeletal disorders and how to systematically address them. *Appl Ergon.* 2018;73:122-40.
42. Jensen MJ, Liao J, Van Gorp B, Sugg SL, Shelton J, Corwin C, et al. Incorporating Surgical Ergonomics Education into Surgical Residency Curriculum. *Journal of Surgical Education.* 2021;78(4):1209-15.
43. Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics Workshop Improves Musculoskeletal Symptoms in General Surgery Residents. *Journal of Surgical Research.* 2022;280:567-74.
44. Franasiak J, Craven R, Mosaly P, Gehrig PA. Feasibility and acceptance of a robotic surgery ergonomic training program. *JSLs.* 2014;18(4).
45. Yadav SK, Lal G, Jain SB, Jha CK, Corwin C, Van Gorp B, et al. Indian surgery Trainee's perspective on surgical ergonomics principles and education: A long road ahead. *Am J Surg.* 2023;226(5):735-40.
46. Hess P, Athanasiadis D, Lee NK, Monfared S, Cleveland PM, Stefanidis D. Preventing Surgeon Work-Related Musculoskeletal Disorders: A Pilot Study of the Comprehensive Operating Room Ergonomics (CORE) Program. *Am J Occup Ther.* 2024;78(5).
47. Gabrielson AT, Mukherjee A, Alam F, Hallet J. Incorporating ergonomics into surgical checklist workflows. *Am J Surg.* 2025;247:116281.
48. Haider A, Hanif H, Dyche TM, Monagle NV, Patterson A, Eberle L, et al. An Interprofessional Approach to Assessing Musculoskeletal Pain and Intraoperative Ergonomics in General Surgery Residents. *Surgical Endoscopy.* 2023;37(Supplement 2):S274.
49. Hansen AF, Hasle P, Caroly S, Reinhold K, Järvis M, Herrig AO, et al. Participatory ergonomics: What works for whom and why? A realist review. *Ergonomics.* 2024;67(1):13-33.
50. Dalager T, Sogaard K, Boyle E, Jensen PT, Mogensen O. Surgery Is Physically Demanding and Associated With Multisite Musculoskeletal Pain: A Cross-Sectional Study. *J Surg Res.* 2019;240:30-9.
51. Dorion D, Darveau S. Do micropauses prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. *Annals of surgery.* 2013;257(2):256-9.
52. Engelmann C, Schneider M, Kirschbaum C, Grote G, Dingemann J, Schoof S, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: A randomized clinical trial. *Surgical Endoscopy.* 2011;25(4):1245-50.

53. Koch M, Forsman M, Enquist H, Baare Olsen H, Sjøgaard K, Sjøgaard G, et al. Frequency of breaks, amount of muscular rest, and sustained muscle activity related to neck pain in a pooled dataset. *PLoS One*. 2024;19(6):e0297859.
54. Yang L, Wang T, Weidner TK, Madura JA, 2nd, Morrow MM, Hallbeck MS. Intraoperative musculoskeletal discomfort and risk for surgeons during open and laparoscopic surgery. *Surg Endosc*. 2021;35(11):6335-43.
55. Yang L, Money SR, Morrow MM, Lowndes BR, Weidner TK, Fortune E, et al. Impact of Procedure Type, Case Duration, and Adjunctive Equipment on Surgeon Intraoperative Musculoskeletal Discomfort. *J Am Coll Surg*. 2020;230(4):554-60.
56. Mah A, Alam F, Larouche J, Dandal MA, Cohen T, Hallbeck S, et al. Interdisciplinary Operating Room Ergonomics Needs and Priorities: A Survey of Operating Room Staff. *Ann Surg*. 2024.
57. Dairywala MI, Gupta S, Salna M, Nguyen TC. Surgeon Strength: Ergonomics and Strength Training in Cardiothoracic Surgery. *Semin Thorac Cardiovasc Surg*. 2022;34(4):1220-9.
58. Lloyd GL, Chung ASJ, Steinberg S, Sawyer M, Williams DH, Overbey D. Is Your Career Hurting You? The Ergonomic Consequences of Surgery in 701 Urologists Worldwide. *J Endourol*. 2019;33(12):1037-42.
59. Sjøgaard G, Mann S, Jensen JSD, Oestergaard AS, Dalager T. The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders. *Journal of Electromyography and Kinesiology*. 2021;61(September).

PAPER IV – RCT PAPER

Intelligent Physical Exercise Training (IPET) and intraoperative ergonomic recommendations for musculoskeletal pain in surgeons: A Danish multicenter open-label randomized controlled trial

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ABSTRACT

Background Musculoskeletal pain (MSP) is highly prevalent among surgeons and a threat to wellbeing and career longevity. Intraoperative ergonomic recommendations (ERGO) and Intelligent Physical Exercise Training (IPET) are candidate strategies for reducing MSP, but their combined effectiveness in surgeons is unknown. We investigated whether adding IPET to ERGO reduced MSP more than ERGO alone.

Methods This pragmatic, multicenter, superiority, open-label randomized controlled trial randomized 83 abdominal and pelvic surgeons 1:1 to ERGO alone or ERGO+IPET over 20 weeks at nine departments across five Danish hospitals (December 2023 to April 2026). ERGO comprised working posture recommendations and intraoperative microbreaks. IPET prescribed 50 minutes of individualized weekly exercise tailored to MSP, job demands, and physical capacity, delivered via a mobile application. The primary outcome was the between-group difference in worst 3-month MSP intensity (0-10 NRS) at 20 weeks in the baseline worst body region, analyzed using a linear mixed model.

Results Sixty of 83 randomized participants (72%) contributed primary outcome data at 20 weeks, and 92% of participants reported MSP in two or more body regions (multisite MSP). There was no statistically significant between-group difference in worst MSP at 20 weeks (0.54, 95% CI -0.41 to 1.50; $p=0.266$), with mean worst MSP reducing from 3.9 to 2.5 in IPET+ERGO and from 3.6 to 2.0 in ERGO. Among secondary outcomes, worst MSP in the past 7 days was the only statistically significant difference, favoring ERGO (0.97, 95% CI 0.00 to 1.95; $p=0.049$). Only nine IPET+ERGO participants (22%) were classified as adherent to the exercise program.

Conclusion Adding IPET to ERGO did not produce an additional reduction in worst MSP compared with ERGO alone. Both groups reduced MSP from baseline to 20 weeks, and this within-group improvement may have narrowed the window for detecting an added between-group effect. Low adherence to the IPET program was likely a further contributing factor, suggesting that successful implementation of app-delivered exercise interventions in surgical populations may require organizational commitment beyond individual-level program delivery.

Trial registration: Clinicaltrials.gov, NCT06112106. Date of registration: 2023 Oct 4.

Sources of funding: The Working Environment Research Fund, Aarhus University.

Keywords Exercise, ergonomics, microbreak, rehabilitation, musculoskeletal pain, workplace intervention, surgeon, surgical ergonomics

OPEN SCIENCE

Trial registration

Clinicaltrials.gov (NCT06112106), 2023 Oct 4: <https://clinicaltrials.gov/study/NCT06112106>

Protocol and statistical analysis plan

DOI and link to protocol article:

The statistical analysis plan can be accessed at clinicaltrials.gov:

<https://clinicaltrials.gov/study/NCT06112106>

Data Sharing

De-identified participant data, data dictionary, and analytical code used to process the data are accessible upon reasonable request.

Funding

Financial funding was provided by the Work Environment Research Fund and Aarhus University. The funding sources have not been involved in the design of this trial and will not be part of any execution, analysis, or interpretation of the data, or decisions to publish results.

Conflicts of Interests

The authors declare that they have no competing interests.

Ethics Approval And Consent To Participate

The Scientific Ethics Committees for the Central Denmark Region reviewed the protocol and found the trial to be exempted from ethics approval (ref no. 1-10-72-124-22). The institutional ethics review board of Aarhus University approved the trial (ref. no. 2023-009). Informed consent was obtained electronically through an online questionnaire.

Consent for publication

To be applied for at Datatilsynet before journal submission.

Authors' contributions

TD and OM conceived the overall aim of the trial, and OM is the grant holder. HJC, OM and TD designed the trial. HJC, OM, LFS, HN, SH, TD and KC contributed to the manuscript preparation and trial conduct planning. All authors read and approved the manuscript for publication.

Acknowledgements

In memoriam: Professor Pernille Tine Jensen (1964-2026) whose early contributions to this study are gratefully acknowledged.

The authors wish to thank the local contacts at the participating surgical departments for their support during recruitment and data collection.

BACKGROUND

Musculoskeletal pain (MSP) is highly prevalent among surgeons [1-6], with the highest pain intensities reported in the neck, back and shoulders and upper extremities [7]. Up to 12% of surgeons require practice restrictions or early retirement due to MSP [1, 7]. Multisite MSP, pain in two or more body regions, further increases symptom burden, and has been shown to negatively affect work (21%), leisure time activities (40%), and sleep (27%) [6].

Working postures in surgery involve awkward, static, and repetitive movements with high precision demands, all well-known risk factors for MSP [8, 9]. In response, intraoperative microbreaks that offer brief recovery and variation in work tasks, have been proposed [10]. However, despite repeated calls in the literature to improve ergonomics in the operating room (OR) and mitigate what has been called “the impending epidemic” of surgeon MSP [7, 11], awareness and adoption of surgical ergonomics remain limited [11-17]. Surgical ergonomics may, however, only be part of the solution, as the evidence on its effects on surgeons’ musculoskeletal health is limited due to the predominance of small and uncontrolled studies [18, 19].

In contrast, the evidence on the benefits of physical exercise training in rehabilitation of MSP is well-supported across occupational groups [19-21], and strength training in particular has been shown to be effective for chronic MSP [22]. Maintaining overall fitness and muscle strength reduces the relative physical demands of work and appears to be protective against MSP [Sjøgaard, 2016 #8436], also when pursuing a career in surgery [5, 23]. Tailored exercise prescribed to the individual’s job demands, physical capacity, health status, and MSP profile may be more beneficial than solely optimizing surgical ergonomics and engaging in general exercise [19, 22]. Intelligent Physical Exercise Training (IPET) was designed to deliver such individualization in workplace settings [24]. IPET has demonstrated positive effects on MSP and overall health across several occupational groups [21].

Digital and app-delivered exercise interventions offer a scalable alternative to supervised workplace programs and may be particularly relevant for highly time-constrained occupational groups [25], but evidence on their effectiveness in surgical populations is lacking. Surgeons are a highly time-constrained occupational group with limited protected time for non-clinical activities, which complicates the implementation of preventive health interventions [26, 27]. Whether app-delivered IPET combined with good ergonomics principles (ERGO) can reduce MSP among surgeons under pragmatic, real-world conditions therefore remain unknown.

Objective

The objective was to investigate the added effectiveness of IPET when combined with Good Ergonomics recommendations (ERGO), compared to ERGO alone, in reducing MSP among abdominal and pelvic surgeons. The hypothesis was that adding IPET to ERGO would result in a synergistic and clinically relevant reduction in MSP compared to ERGO alone.

METHODS

Design and sample size

This was a pragmatic, multicenter, superiority, open-label block-randomized controlled trial (RCT) with two parallel arms [Christiansen, 2025 #8350]. Good Ergonomics (ERGO) was introduced at the department level 12 weeks before randomization, so that at trial start all participants had access to the ERGO components for 12 weeks. Participants randomized to IPET+ERGO subsequently received the IPET intervention in addition to continued ERGO exposure. The protocol [26] specifies recruitment from both Denmark and the US. However, due to delayed roll-out of the US intervention, this report concerns Danish participants only, and the US results will be reported separately.

Surgeons were allocated in a 1:1 ratio to a 20-week intervention period with outcome assessments at baseline, 12- and 20 weeks. The trial was conducted between December 2023 and April 2026. Three surgeons, representing the target study population, contributed to the trial design, trial conduct, and participated in the reporting of results.

Informed consent was obtained from all participants, and ethical approval was granted by Aarhus University ethics committee (2023-0563092), and procedures were in accordance with ethical standards of the institutional committee and the Helsinki declaration. The reporting of this trial conforms to the Consolidated Standards of Reporting Trials guideline (CONSORT) [29], and the trial was registered prospectively at Clinicaltrials.gov (NCT06112106, October 4, 2023).

Participants

Surgeons were recruited from nine academic and regional hospital departments across five hospitals in Denmark. They received e-mail invitations (and two follow-up e-mails) following completion of the Good Ergonomics questionnaire prior to the RCT baseline assessment [30]. Eligible surgeons performed surgery as primary or assisting surgeon for a minimum average of four hours per week (self-assessment), were specialized in gynecology, urology, or colorectal surgery, and had robot-assisted laparoscopy (RAS), laparoscopy (LAP), or open surgery (OPEN) as their main surgical modality. The exclusion criterion was advice against exercise from a general practitioner.

Interventions

The trial compared two intervention conditions. Participants allocated to the standard group were encouraged to follow Good Ergonomics recommendations (ERGO) during surgical practice. Participants allocated to the intervention group were encouraged to follow the same ERGO recommendations and, in addition, received access to an individually tailored IPET program delivered through a mobile application (app).

Good Ergonomics (ERGO)

ERGO comprised two components: 1) recommendations on ergonomic work postures in the operating room (OR), and 2) regular microbreaks. It was introduced at the department level approximately 12 weeks before trial start. Figure 1 Good Ergonomics poster for laparoscopic surgery [31]. Two similar posters with recommendations for OPEN and RAS are provided in the supplementary materials. The ERGO posters were displayed in or near the ORs, in OR coffee/break rooms, and in the surgical departments, and included a QR code linking to short informational videos on the importance of OR ergonomics and microbreaks for preventing and mitigating MSP. This provided a brief reference for surgeons who missed the ERGO presentation, and a reminder for those who attended the ERGO presentation.

GOOD ERGONOMICS

WORKING POSTURE – LAPAROSCOPY

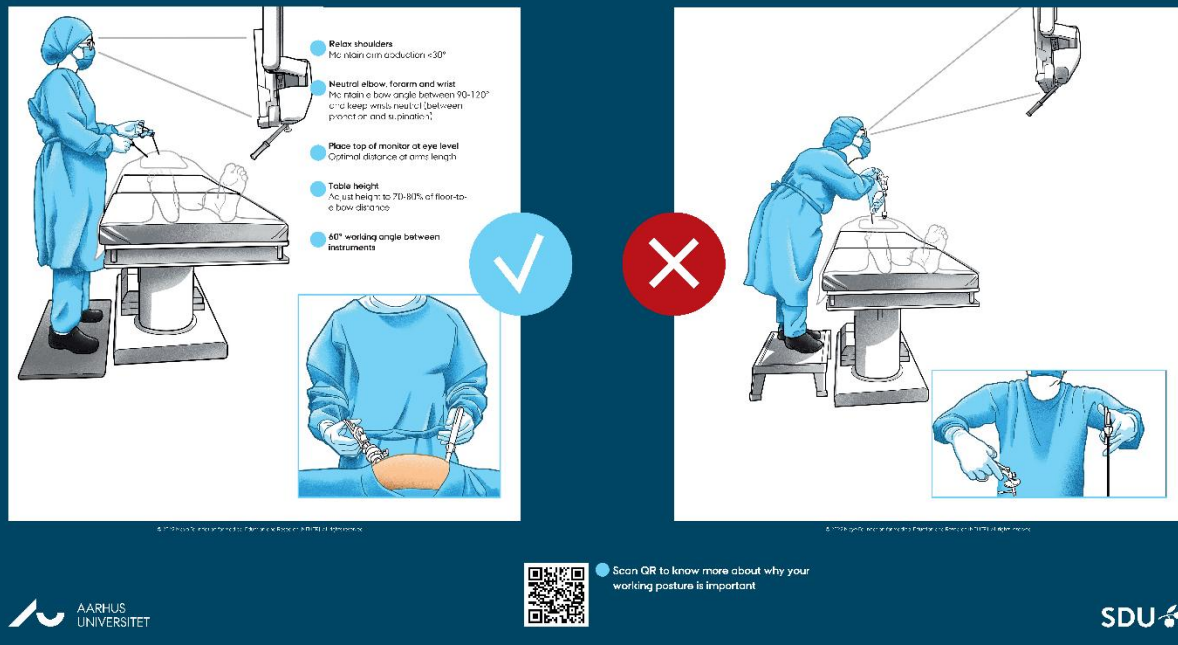


Figure 1 Good Ergonomics poster for laparoscopic surgery [31]

The other ERGO element was the recommendation to perform regular (at least every 60 minutes) intra-operative microbreaks with stretching exercises. Surgeons were encouraged to coordinate the microbreak with the OR team at the beginning of a surgical day, agreeing on the planned frequency for that day's surgeries, e.g. at 60 minute-intervals or at a surgically convenient time. The microbreaks were guided by a locally adapted Danish-language audio version of the Mayo Clinic's OR Stretch web app: <https://orstretch.mayoclinic.org/> [32], accessible via a QR code on the poster (Figure 2) [33]. Each microbreak lasted 90 seconds. For surgeries expected to last less than 60 minutes, the microbreak was performed immediately post-surgery.

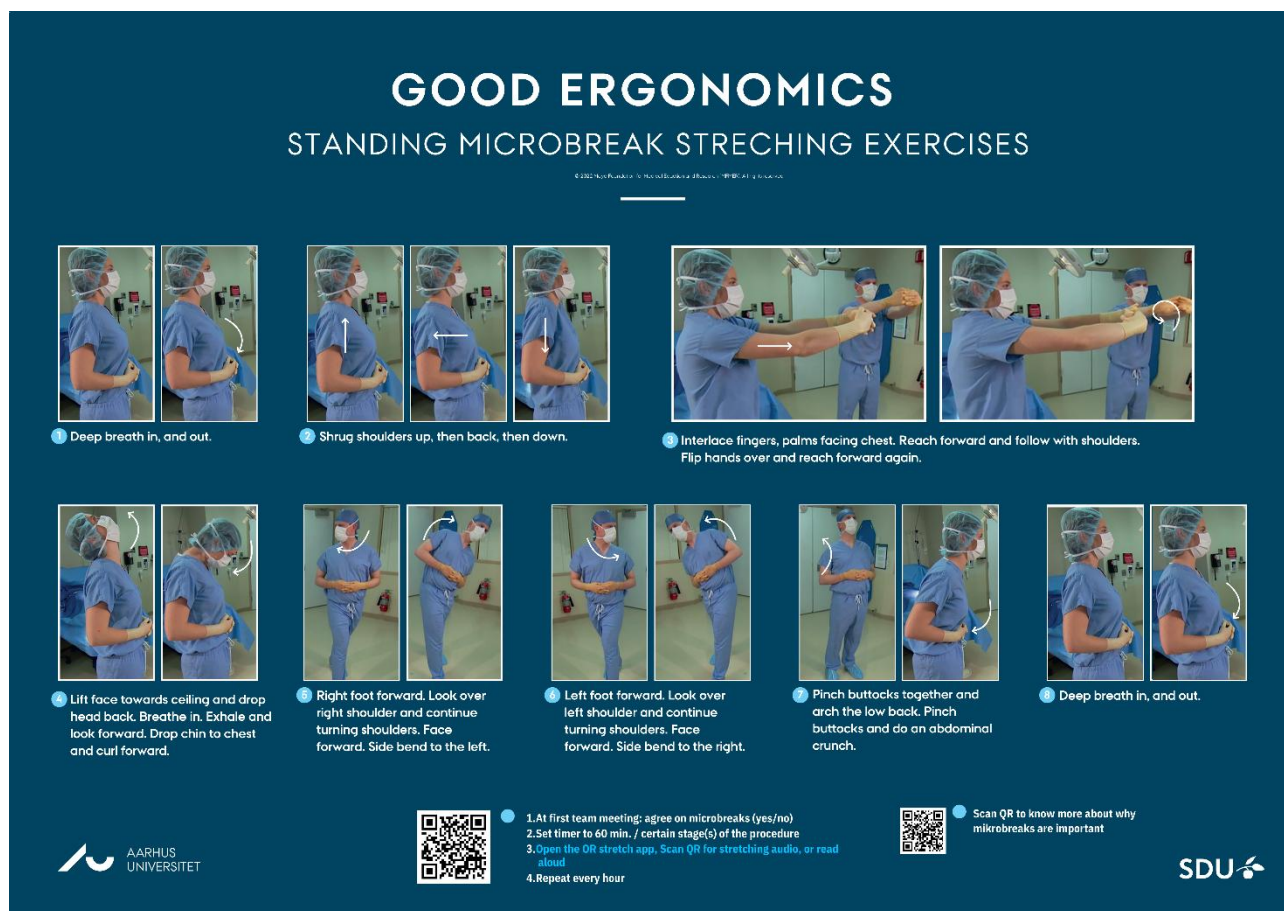


Figure 2 Microbreak poster illustrating the stretching exercises to perform during a microbreak, QR codes and written instructions [32-34]

One ERGO session was delivered at the department level 12 weeks prior to trial start by a member of the trial staff. Sessions lasted from 10-30 minutes and took place at department staff meetings as an oral presentation, followed by distribution of the ERGO posters. Adherence to ERGO was voluntary.

Approximately twelve weeks post-ERGO, an introduction to trial session was delivered, covering IPET, providing trial information and answering potential questions. This was considered the trial start, following which surgeons were invited to participate.

Intelligent Physical Exercise Training (IPET) and ERGO

In the intervention arm (IPET+ERGO), ERGO was supplemented with IPET. Participants received an individually tailored 50-minute weekly training program based on self-assessed measurements of work demands (sedentary, walking/standing, or heavy work), physical capacity (fitness, strength, and balance), MSP profile, and health status [24]. According to the surgeons' answers and

evidence-based cut-points for specific training modes, the IPET program was prescribed accordingly (see [30] for more details).

Each 50-minute program included 20 minutes of exercise training targeting work demands. The remaining 30 minutes consisted of a combination of aerobic-, strength- and functional training depending on individual profile [24]. Reporting any degree of MSP led to the prescription of strength training for the affected body region. The strength training load could be adjusted using elastic resistance bands (Theraband), with varying levels of tension/resistance.

The intervention was delivered via the mobile application Intelligent Motion (hereafter called the app) [35]. The app provided various resources and features, including guidance on selecting the appropriate elastic resistance band, video demonstrations of proper exercise execution, access to an IPET knowledge bank, and the option to create teams (Figure 3A-D). Participants were encouraged to complete the exercises in their leisure time or, if possible, during working hours [24, 36-38]. The weekly 50 minutes of IPET could be performed in one session or divided into 2-5 shorter sessions with the same effect [39]. See the protocol for detailed trial methods [30].

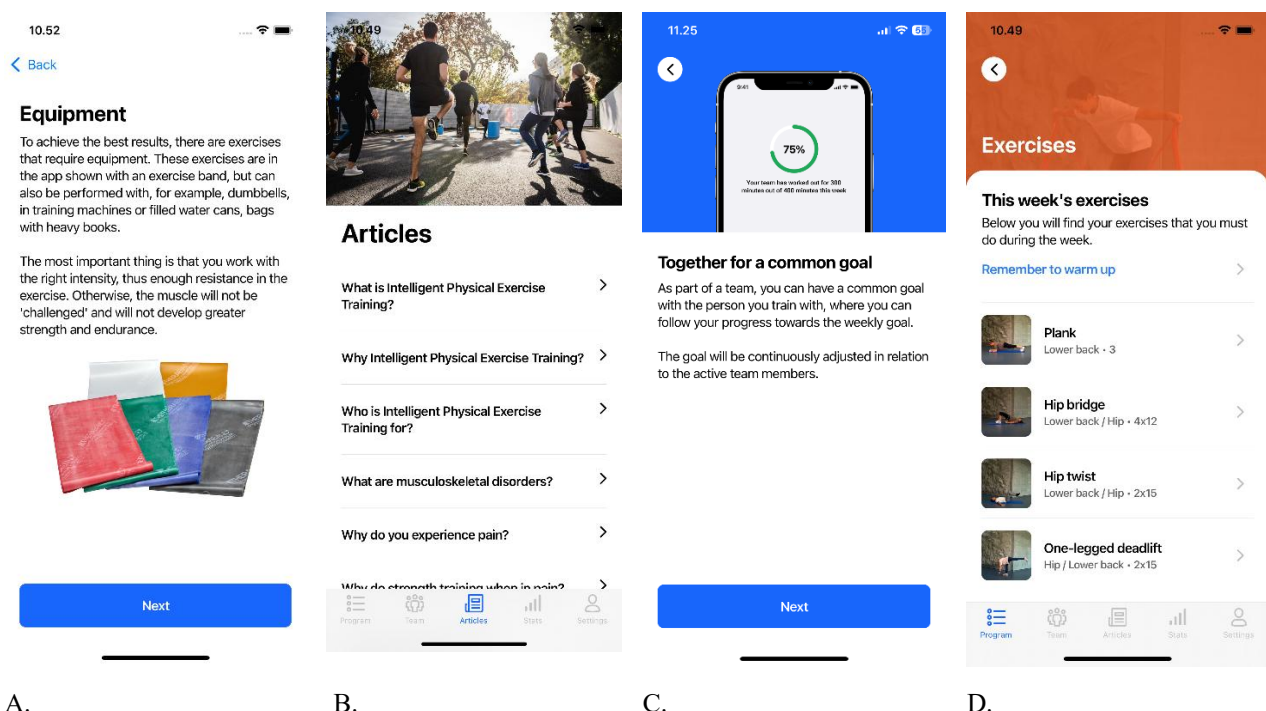


Figure 3 App screenshots A. Equipment guidance. B. App knowledge bank C. Training Community D. Example of an IPET program

Outcomes

The outcomes were collected using an online survey at baseline, 12 weeks and 20 weeks.

The primary outcome was worst 3-month MSP intensity at 20 weeks, defined as the highest reported MSP intensity score across ten body regions (neck, upper back, lower back, right and left shoulders, right and left elbows, right and left wrists/hands, hips, knees, and ankles/feet) at baseline, measured on a 0 (no pain) to 10 (worst pain) numerical rating scale (NRS). Left and right sides were collapsed when presenting worst MSP intensity. MSP was assessed using a modified version of the Nordic Musculoskeletal Questionnaire (NMQ) [40]. For each body region, participants first reported the number of days with MSP in the past three months; only those reporting at least one day were asked to rate intensity. If zero days were reported, intensity was coded as 0.

Secondary MSP-related outcomes were overall pain case status (worst MSP intensity ≥ 3 across body regions, also used for stratification in randomization), multisite MSP (≥ 2 painful body regions), worst 7-day MSP intensity (0-10 NRS), days with MSP in the past three months (five-level ordinal scale from 0 days to every day), days prevented from work due to MSP (collapsed to a binary variable: zero days vs. ≥ 1 day due to sparse data in higher categories), and use of pain medication for MSP. Regional pain case status (MSP intensity ≥ 3 within a specific body region) is reported descriptively at the body region level.

Non-MSP secondary outcomes were general health (single SF-12 item¹ [41], measured on a five-level ordinal scale from excellent to poor), personal and work-related burnout (Copenhagen Burnout Inventory (CBI) [42]), and work ability (single WAI item² [43], rated on a 0-10 NRS, where 0 = currently cannot work at all, and 10 = work ability at its best).

Descriptive measures collected included age, sex, body mass index (BMI), specialty, and weekly working hours. Physical activity profile was assessed with the Saltin-Grimby Physical Activity Level Scale [44], comprising four levels ranging from physically inactive to regular hard physical training. Physical capacity was self-assessed using visual analogue scales [45]. Weekly minutes of moderate-to-vigorous and hard physical activity were assessed with the Danish Health Profile 2021 questions [46].

^{1,2} The final dataset was not available until May 2026; accordingly, only single-item scores for work ability and general health are reported here.

Self-reported adherence to ERGO and IPET was recorded at 12- and 20-week follow-ups. ERGO was assessed by two questions *“To what extent did you position yourself or the equipment in the operating room to achieve an ergonomic working posture during surgery?”* and *“To what extent did you take one or more intraoperative microbreaks with stretching?”*. Both questions had five response options ranging from never to always. Because of small cell numbers, responses were dichotomized into “most of the time or always” and “sometimes or less”.

IPET adherence was assessed by the question *“On average, how many minutes of Intelligent Motion did you do each week?”*.

Harms were not systematically recorded. However, the proportion of participants with an increase in worst MSP from baseline to follow-up is reported. Adverse events have been rare in previous studies of similar interventions, with no serious side effects reported [47].

Randomization

An independent REDCap data manager not involved in the trial provided a computer generated allocation sequence with permuted random block sizes of 4, 6 and 8 [48], stratified by overall pain case status (baseline MSP ≥ 3). Within REDCap, the allocation sequence was concealed from the trial staff enrolling participants, and group assignment to ERGO (standard) or ERGO+IPET (intervention) was performed in the REDCap system. Due to the nature of the intervention, neither participants nor trial staff were blinded to group assignment. After the trial, participants in the standard group who completed the 20-week follow-up questionnaire were offered the IPET program, but without further followed up.

Statistical Methods

The target sample size of 83 was calculated to detect a clinically relevant between-group difference in worst MSP intensity at 20 weeks, accounting for 30% attrition; detailed assumptions are reported in the protocol [Christiansen, 2025 #8350]. All analyses were performed in Stata 17 (StataCorp LLC, College Station, TX, USA) [24] [StataCorp, 2021 #8317], using two-sided tests at $\alpha = 0.05$.

The primary intention-to-treat analysis estimated the between-group difference in worst MSP intensity at 20 weeks using a linear mixed model, with MSP at 12 and 20 weeks as the dependent variable, time, group, and their interaction as fixed effects, baseline worst MSP as a covariate, and a random intercept for each participant. Missing data were handled under the missing-at-random assumption inherent to this approach. Continuous secondary outcomes were analyzed using the same model; binary outcomes using mixed-effects logistic regression; and ordinal outcomes using ordinal logistic regression with cluster-robust standard errors, as mixed-effects ordinal models did not converge. Pre-specified additional analyses included a per-protocol analysis restricted to IPET+ERGO participants with $\geq 70\%$ adherence, an adjusted analysis, and a complete-case analysis. A pre-specified subgroup analysis by baseline pain case status was not performed, as 77% of participants were pain cases at baseline, rendering the subgroups too imbalanced to support a meaningful comparison.

RESULTS

Participant flow

The flow of participants through the trial is presented in Figure 4. Of the 104 surgeons invited, 85 (82%) were assessed for eligibility, and 83 (80% of those invited) were randomized to IPET+ERGO (n=41) or ERGO only (n=42). Two participants were randomized despite not meeting the minimum four hours of surgery weekly, due to an error in the automated screening workflow that was identified after randomization. In accordance with the intention-to-treat principle, both participants were retained in the primary analysis. Of the 83 randomized participants, 66 (80%) contributed primary outcome data at 12 weeks and 60 (72%) at 20 weeks. At 12 weeks, 10 IPET+ERGO and 5 ERGO participants had missing primary outcome data; of these, 4 IPET+ERGO participants subsequently provided 20-week data. At 20 weeks, a further 7 IPET+ERGO and 5 ERGO participants had missing data. The complete-case population (primary outcome data at all three timepoints) comprised 24 IPET+ERGO and 32 ERGO participants. The per-protocol analysis comprised 9 IPET+ERGO participants meeting the adherence threshold and all 42 ERGO participants with 20-week data.

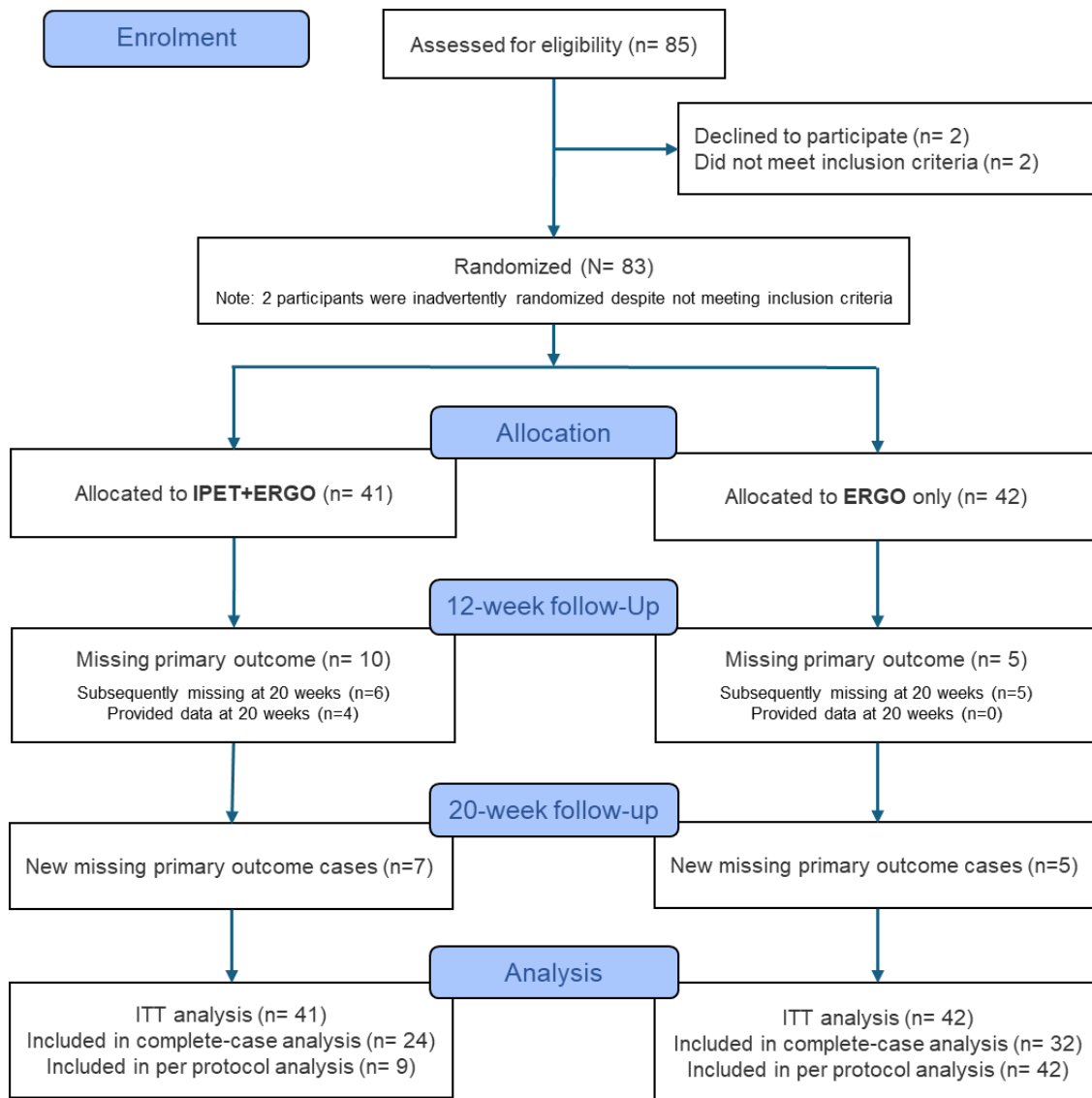


Figure 4 CONSORT flow chart

Baseline characteristics

Baseline participant characteristics are presented in Table 1 and were comparable between groups. Mean worst MSP intensity at baseline was 3.8 (1.9). The body regions most frequently identified contributing to worst MSP were the neck (29%), lower back (23%), knees (13%) and shoulders (11%). The wrists/hands, although less commonly the worst region, had the highest mean intensity (6.0, SD 1.4). The full distribution of worst baseline MSP regions and corresponding pain intensities is shown in Table 2.

The distribution of any MSP (≥ 1 day in the past three months) across body regions is illustrated in Figure 5. The most commonly affected regions were the neck (82%), lower back (72%), and upper back (53%), and 92% of participants reported MSP in two or more body regions (multi-site MSP).

Intervention exposure and adherence

Self-reported adherence to ergonomic posture in the OR at 20 weeks was available for 51 of 83 randomized participants (24 in IPET+ERGO; 27 in ERGO). Among these, 94% reported practicing ergonomic postures *always or most of the time*, and 6% *sometimes or less*. For microbreaks, 22% reported performing intraoperative microbreaks *always or most of the time*, and 78% reported *sometimes or less*.

At 20 weeks, 24 of 41 of IPET+ERGO participants provided self-reported weekly IPET data. Among these, the mean was 32 minutes per week (SD 29, range 0-120). Of the 41 randomized IPET+ERGO participants, nine (22%) were classified as adherent (≥ 35 minutes per week, corresponding to $\geq 70\%$ of the prescribed IPET dose). Participants without 20-week adherence data were classified as non-adherent. Among the nine adherent participants, mean weekly IPET was 58 minutes (SD 29, range 35-120), with some participants exceeding the prescribed dose.

Missing outcome data

Missing primary outcome data at 20 weeks was summarized by treatment group, age, sex, BMI, weekly working hours, leisure-time physical activity level, and surgical specialty. Older age was associated with missing 20-week data (mean difference 4.4 years, 95% CI 0.4 to 8.3; $p=0.030$). No other characteristic was associated with missingness. Among IPET+ERGO participants, baseline characteristics of adherent participants and non-adherent participants were comparable. Baseline characteristics of complete versus non-complete cases and of adherent versus non-adherent IPET+ERGO participants are presented in Supplementary Table 9.

Table 1 Baseline demographic, work, and health-related characteristics of randomized participants by treatment group and total

Demographic, work and health-related characteristics	Total (N=83)	IPET+ERGO (n=41)	ERGO (n=42)
Age, years	48.4 (8.6)	48.0 (8.6)	48.8 (8.6)
Female sex, n (%)	53 (63.9)	26 (63.4)	27 (64.3)
BMI, kg/m ²	24.5 (3.3)	25.0 (2.9)	24.0 (3.6)
Surgical specialty, n (%)			
Gynecology	22 (26.5)	10 (24.4)	12 (28.6)
Urology	30 (36.1)	17 (41.5)	13 (31.0)
Colorectal surgery	28 (33.7)	14 (34.1)	14 (33.3)
Other	1 (1.2)	0 (0.0)	1 (2.4)
Weekly working hours	40.6 (5.0)	40.6 (5.8)	40.7 (3.9)
Self-assessed physical capacity compared with peers, NRS 0-10			
Muscle strength	5.9 (1.9)	5.3 (1.7)	6.5 (1.9)
Cardiovascular fitness	5.9 (2.3)	5.3 (2.2)	6.5 (2.2)
Balance	6.4 (1.7)	6.5 (1.6)	6.2 (1.7)
Leisure-time physical activity level, n (%)			
Physically inactive	5 (6.2)	3 (7.3)	2 (5.0)
Some light physical activity	39 (48.1)	23 (56.1)	16 (40.0)
Regular physical activity and training	34 (42.0)	14 (34.1)	20 (50.0)
Regular hard physical training for competitive sports	3 (3.7)	1 (2.4)	2 (5.0)
Moderate physical activity per week, minutes, n (%)			
Less than 1/2 hour (less than 30 minutes)	9 (11.1)	6 (14.6)	3 (7.5)
1/2 to 1 1/2 hours (30-89 minutes)	28 (34.6)	15 (36.6)	13 (32.5)
1 1/2 to 2 1/2 hours (90-149 minutes)	9 (11.1)	5 (12.2)	4 (10.0)
2 1/2 to 5 hours (150-299 minutes)	27 (33.3)	12 (29.3)	15 (37.5)
5 hours or more (300 minutes or more)	8 (9.9)	3 (7.3)	5 (12.5)
Vigorous physical activity per week, minutes, n (%)			
Less than 1/2 hour (less than 30 minutes)	41 (50.6)	25 (61.0)	16 (40.0)
1/2 to 1 hour (30-59 minutes)	13 (16.0)	7 (17.1)	6 (15.0)
1 to 1 1/2 hours (60-89 minutes)	12 (14.8)	4 (9.8)	8 (20.0)
1 1/2 to 2 1/2 hours (90-149 minutes)	6 (7.4)	2 (4.9)	4 (10.0)
2 1/2 hours or more (150 minutes or more)	9 (11.1)	3 (7.3)	6 (15.0)

Values are observed baseline data and are presented as mean (SD) for continuous variables and n (%) for categorical variables.

Table 2 Body region contributing to worst baseline MSP and corresponding intensity

Worst baseline MSP region (N= 83)	n (%)	Worst MSP intensity, mean (SD)
Neck	24 (28.9)	3.2 (2.0)
Upper back	7 (8.4)	3.1 (2.0)
Lower back	19 (22.9)	3.9 (1.8)
Shoulder	9 (10.8)	4.7 (1.6)
Elbow	2 (2.4)	3.0 (0.0)
Wrist/hand	4 (4.8)	6.0 (1.4)
Hip	3 (3.6)	4.7 (2.1)
Knee	11 (13.3)	3.7 (1.6)
Ankle/foot	4 (4.8)	3.5 (2.6)
Total	83 (100.0)	3.8 (1.9)

Worst MSP region was defined as the body region with the highest reported 3-month MSP intensity at baseline. MSP intensity is reported on a 0-10 numerical rating scale, with higher scores indicating worse pain.

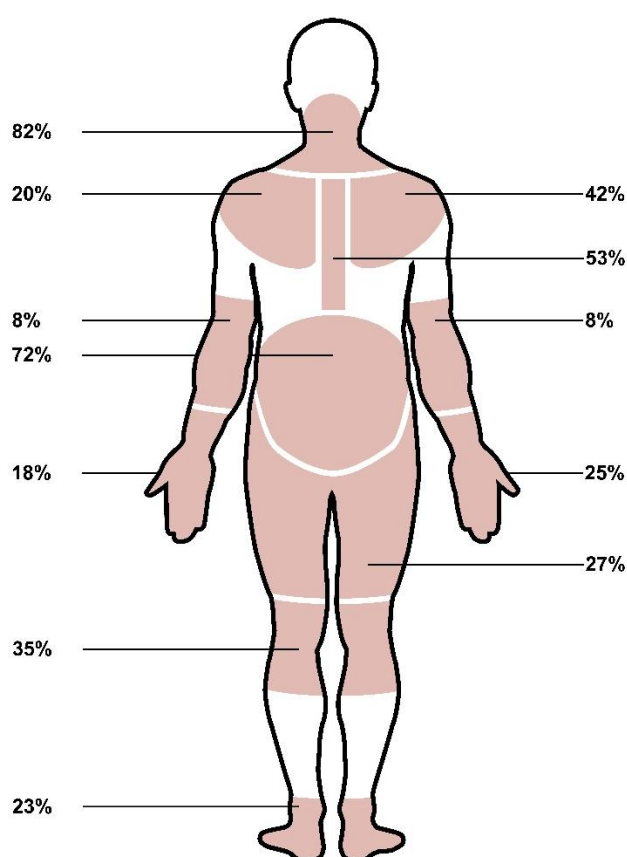


Figure 5 Prevalence of MSP by body region at baseline among randomized participants (n=83).

Primary outcome

In the primary intention-to-treat analysis (Table 3), there was no statistically significant between-group difference in worst MSP at 20 weeks (0.54, 95% CI -0.41 to 1.50; $p = 0.266$). Model-estimated marginal means at 20 weeks were 2.5 (SD 0.4) in IPET+ERGO and 2.0 (SD 0.3) in ERGO, compared with observed baseline means of 3.9 (SD 1.9) and 3.6 (SD 2.0), respectively. At 12 weeks, there was likewise no statistically significant between-group difference (0.09, 95% CI -0.86 to 1.03; $p = 0.859$, 12-week effect estimate not shown in Table 3).

The pre-specified adjusted analysis controlling for baseline age, sex, BMI, surgical specialty, weekly working hours and physical activity profile did not materially change the estimate (0.63, 95% CI -0.38 to 1.63; $p = 0.223$). The complete-case analysis restricted to participants with primary outcome data at all three time points (IPET+ERGO $n = 24$ versus ERGO $n = 32$) likewise did not materially change the estimate (0.59, 95% CI -0.47 to 1.64; $p = 0.274$).

Per protocol analysis

The per protocol analysis included the nine IPET+ERGO participants with $\geq 70\%$ adherence and all ERGO participants with 20-week data (Table 4). There was no statistically significant between-group difference in worst MSP at 20 weeks (1.35, 95% CI -0.07 to 2.77; $p = 0.062$), although the point estimate favored ERGO. Worst MSP in the past seven days was significantly lower in ERGO at 20 weeks (1.66, 95% CI 0.33 to 2.98; $p = 0.014$). The per-protocol estimate for multisite MSP was not estimable due to sparse data and quasi-separation in the adherent IPET+ERGO group.

Secondary MSP-related outcomes

At 20 weeks, effect estimates for secondary MSP-related outcomes varied in direction (Table 3). Some favored ERGO (overall pain case status, days with MSP, pain medication) and others favored IPET+ERGO (multi-site MSP, days prevented from work). Worst MSP intensity in the past seven days was significantly lower in ERGO than in IPET+ERGO at 20 weeks (between-group difference 0.97, 95% CI 0.00-1.95; $p = 0.049$). No other between-group differences were statistically significant.

Regional mean MSP

Regional mean MSP intensity and regional pain case prevalence across all body regions are presented descriptively in

Table 5. Unlike the primary outcome, which was defined as worst MSP intensity in the single body region reported as most painful at baseline, these data reflect the full regional distribution of MSP across the sample. At baseline, the neck, upper back, and lower back were the most affected regions among all participants in terms of both MSP intensity and regional pain case prevalence. At 20 weeks, MSP intensity was reduced across most body regions in both groups. Pain case prevalence followed a similar pattern, though reductions were less consistent, with small numerical increases observed in some regions.

General health and work ability

General health, work ability, and burnout outcomes are presented in Table 6. None of the between-group differences were statistically significant at 20 weeks follow-up. Both groups showed within-group reductions in personal burnout from baseline to 20 weeks: IPET+ERGO by 2.0 points (8.3 to 6.3), and ERGO by 1.0 point (7.2 to 6.2). Work-related burnout was also reduced within the IPET+ERGO group by 1.9 points (7.8 to 5.9). Work ability was high with both groups scoring 8.9 within a range of 0-10.

Harms

Harms were not systematically recorded. The proportion of participants with an increase in worst MSP from baseline to 20 weeks was reported instead, with an increase defined as any positive change in NRS score. Nine of 83 randomized participants reported an increase in MSP: 6/41 (15%) in IPET+ERGO and 3/42 (7%) in ERGO. In IPET+ERGO, the mean increase was 2.2 (SD 1.0), with affected body regions being the neck (n= 1), shoulders (n= 1), lower back (n= 1), ankle/foot (n=2), and knee (n= 1). In ERGO, the mean increase was 2.0 (SD 1.7), with affected body regions being the neck (n= 1) and lower back (n=2).

Table 3 Intention-to-treat analysis of MSP-related outcomes at baseline, 12 weeks, and 20 weeks by treatment group

	IPET+ERGO (n=41)			ERGO (n=42)			Between-group effect at 20 weeks (95% CI)	P value
Outcomes	Baseline	12 weeks	20 weeks	Baseline	12 weeks	20 weeks		
Worst MSP intensity over last 3 months, NRS 0-10, mean (SD/SE)	3.9 (1.9)	2.03 (0.34)	2.50 (0.35)	3.6 (2.0)	2.03 (0.32)	1.95 (0.34)	0.54 (-0.41 to 1.50)	0.266
Worst MSP intensity in past 7 days, NRS 0-10, mean (SD/SE)	3.2 (2.2)	1.45 (0.35)	2.27 (0.36)	3.4 (2.3)	1.63 (0.32)	1.30 (0.34)	0.97 (0.00 to 1.95)	0.049
Pain case (overall MSP ≥ 3), n (%)	32 (78.0)	12/31 (38.7)	12/28 (42.9)	32 (76.2)	16/37 (43.2)	9/32 (28.1)	8.46 (0.39 to 181.53)	0.172
Multisite MSP (≥ 2 regions), n (%)	40 (97.6)	24/31 (77.4)	20/28 (71.4)	36 (85.7)	27/37 (73.0)	24/32 (75.0)	0.58 (0.16 to 2.04)	0.392
Days with worst MSP past 3 months, n (%)							1.66 (0.59 to 4.70)	0.337
0 days	0 (0.0)	7/31 (22.6)	8/28 (28.6)	2 (4.8)	12/37 (32.4)	12/32 (37.5)		
1-7 days	11 (26.8)	10/31 (32.3)	10/28 (35.7)	13 (31.0)	14/37 (37.8)	12/32 (37.5)		
8-30 days	14 (34.1)	8/31 (25.8)	4/28 (14.3)	11 (26.2)	9/37 (24.3)	5/32 (15.6)		
More than 30 days, not every day	11 (26.8)	4/31 (12.9)	4/28 (14.3)	10 (23.8)	1/37 (2.7)	2/32 (6.2)		
Every day	5 (12.2)	2/31 (6.5)	2/28 (7.1)	6 (14.3)	1/37 (2.7)	1/32 (3.1)		
Days prevented from work due to MSP in past 3 months, n (%)							0.77 (0.10 to 5.71)	0.796
0 days	33 (80.5)	28/31 (90.3)	26/28 (92.9)	32 (76.2)	33/37 (89.2)	29/32 (90.6)		
≥ 1 day	8 (19.5)	3/31 (9.7)	2/28 (7.1)	10 (23.8)	4/37 (10.8)	3/32 (9.4)		
Use of pain medication for MSP, n (%)							2.70 (0.75 to 9.68)	0.127
Rarely or never	22 (53.7)	17/30 (56.7)	17/28 (60.7)	26 (61.9)	27/37 (73.0)	27/32 (84.4)		
One to several times per month	15 (36.6)	12/30 (40.0)	10/28 (35.7)	12 (28.6)	5/37 (13.5)	3/32 (9.4)		
One to several times per week	4 (9.8)	1/30 (3.3)	1/28 (3.6)	4 (9.5)	5/37 (13.5)	2/32 (6.2)		
Daily	0 (0.0)	0/30 (0.0)	0/28 (0.0)	0 (0.0)	0/37 (0.0)	0/32 (0.0)		

Baseline values are observed means (SD) or n (%). Follow-up values for continuous outcomes are model-estimated marginal means with standard errors (SE). Follow-up values for categorical outcomes are observed n/N (%), where N denotes the number of participants with available data at each time point. Effect estimates are model-based between-group estimates at 20 weeks. P values are from model-based tests of the between-group difference at 20 weeks. For continuous pain outcomes, positive effect estimates favor ERGO. For binary and ordinal outcomes, effect estimates are OR-based estimates; OR >1 favors ERGO. Overall pain case was defined as worst MSP intensity ≥ 3 on a 0-10 NRS. Multisite MSP was defined as MSP in ≥ 2 body regions. Bold indicates P<0.05.

Table 4 Per-protocol analysis of MSP-related outcomes among adherent IPET+ERGO participants and all ERGO participants

	≥70%IPET+ERGO (n= 9)		ERGO (n=41)		Between-group effect estimate (95% CI) Baseline vs. 20 weeks	P value*
Outcomes	Baseline	20 weeks	Baseline	20 weeks		
Worst MSP intensity last 3 months, NRS 0-10, mean (SD/SE)	4.0 (2.1)	3.29 (0.64)	3.6 (2.0)	1.94 (0.33)	1.35 (-0.07 to 2.77)	0.062
Worst MSP intensity in past 7 days, NRS 0-10, mean (SD/SE)	3.1 (2.3)	3.01 (0.60)	3.4 (2.3)	1.35 (0.31)	1.66 (0.33 to 2.98)	0.014
Pain case (overall MSP ≥3), n (%)	7 (77.8)	4/9 (44.4)	32 (76.2)	9/32 (28.1)	5.13 (0.14 to 187.18)	0.373
Multisite MSP (≥ 2 sites), n (%)	9 (100.0)	8/9 (88.9)	36 (85.7)	24/32 (75.0)	Not estimable	
Days with MSP past 3 months, n (%)					3.51 (0.54 to 22.73)	0.187
0 days	0 (0.0)	2/9 (22.2)	2 (4.8)	12/32 (37.5)		
1-7 days	3 (33.3)	3/9 (33.3)	13 (31.0)	12/32 (37.5)		
8-30 days	3 (33.3)	1/9 (11.1)	11 (26.2)	5/32 (15.6)		
More than 30 days, not every day	2 (22.2)	1/9 (11.1)	10 (23.8)	2/32 (6.2)		
Every day	1 (11.1)	2/9 (22.2)	6 (14.3)	1/32 (3.1)		
Days prevented from work due to MSP in past 3 months, n (%)					1.22 (0.08 to 18.81)	0.886
0 days	8 (88.9)	9/9 (100.0)	32 (76.2)	29/32 (90.6)		
>1 day	1 (11.1)	0/9 (0.0)	10 (23.8)	3/32 (9.4)		
Use of pain medication for MSP, n (%)					2.76 (0.24 to 31.50)	0.413
Rarely or never	7 (77.8)	6/9 (66.7)	26 (61.9)	27/32 (84.4)		
One to several times per month	1 (11.1)	3/9 (33.3)	12 (28.6)	3/32 (9.4)		
One to several times per week	1 (11.1)	0/9 (0.0)	4 (9.5)	2/32 (6.2)		
Daily	0 (0.0)	0/9 (0.0)	0 (0.0)	0/32 (0.0)		

The per-protocol population included all participants allocated to ERGO and participants allocated to IPET+ERGO who reported ≥70% adherence to IPET. Observed baseline values are presented as mean (SD) or n (%). For continuous outcomes, 20-week values are model-estimated marginal means with standard errors (SE). For categorical outcomes, 20-week values are presented as n/N (%), where N denotes the number of participants with available data at that time point. Effect estimates represent the model-based between-group difference at 20 weeks, with positive values favoring ERGO for continuous pain outcomes. For binary and ordinal outcomes, effect estimates are OR-based estimates. For ordinal outcomes, one overall 20-week between-group comparison is reported. P values are from model-based tests of between-group differences at 20 weeks. Pain case was defined as worst MSP intensity ≥3 on a 0-10 NRS. Multisite MSP was defined as MSP in ≥2 body regions. Bold indicates P<0.05. The per-protocol estimate for multisite MSP was not estimable because of sparse data and quasi-separation in the adherent IPET+ERGO group.

Table 5 Regional MSP intensity and pain-case status by group

	IPET+ERGO				ERGO			
	MSP intensity		Regional pain-case		MSP intensity		Regional pain-case	
	Baseline	20 weeks	Baseline	20 weeks	Baseline	20 weeks	Baseline	20 weeks
Neck	2.9 (1.8)	1.6 (1.6)	15/34 (44.1%)	6/23 (26.1%)	2.5 (1.5)	1.4 (1.9)	15/34 (44.1%)	5/27 (18.5%)
Left shoulder	3.4 (1.7)	1.2 (1.9)	5/7 (71.4%)	1/4 (25.0%)	2.6 (1.5)	1.6 (0.9)	5/10 (50.0%)	1/8 (12.5%)
Right shoulder	3.1 (1.9)	0.4 (0.8)	9/16 (56.2%)	0/10 (0.0%)	2.4 (1.8)	1.3 (2.2)	8/19 (42.1%)	3/14 (21.4%)
Right elbow	2.0 (1.0)	0.0 (0.0)	1/3 (33.3%)	0/1 (0.0%)	3.2 (2.1)	0.0 (0.0)	3/4 (75.0%)	0/4 (0.0%)
Left elbow	2.7 (1.5)	0.0 (0.0)	2/3 (66.7%)	0/2 (0.0%)	2.5 (1.0)	0.0 (0.0)	3/4 (75.0%)	0/1 (0.0%)
Right wrist/hand	3.1 (2.1)	1.5 (2.8)	7/11 (63.6%)	1/8 (12.5%)	3.1 (1.8)	0.4 (1.1)	6/10 (60.0%)	1/8 (12.5%)
Left wrist/hand	2.8 (1.7)	1.0 (2.4)	4/9 (44.4%)	1/6 (16.7%)	3.7 (1.6)	0.8 (1.5)	5/6 (83.3%)	1/4 (25.0%)
Upper back	2.8 (2.0)	1.4 (2.1)	13/25 (52.0%)	4/16 (25.0%)	2.7 (1.3)	0.9 (1.1)	10/19 (52.6%)	2/14 (14.3%)
Lower back	2.6 (1.3)	1.8 (1.8)	15/31 (48.4%)	8/21 (38.1%)	3.4 (1.9)	2.2 (2.5)	18/29 (62.1%)	9/25 (36.0%)
Hips	2.2 (1.8)	1.3 (1.7)	3/11 (27.3%)	2/7 (28.6%)	2.1 (1.4)	1.8 (2.4)	3/11 (27.3%)	2/8 (25.0%)
Knees	2.4 (1.4)	1.3 (2.3)	5/15 (33.3%)	2/9 (22.2%)	3.1 (1.9)	1.3 (1.4)	9/14 (64.3%)	3/12 (25.0%)
Ankles/feet	3.6 (2.2)	1.7 (2.6)	6/9 (66.7%)	2/7 (28.6%)	2.0 (0.9)	1.8 (2.4)	2/10 (20.0%)	2/8 (25.0%)

Values are restricted to participants reporting MSP intensity > 0 in the respective body region at baseline. Baseline values are based on all randomised participants with MSP > 0 in the respective region (IPET+ERGO: n=41; ERGO: n=42 total randomised). Values at 20 weeks are based on participants with available follow-up data who reported MSP > 0 in the respective body region at baseline; the baseline and 20-week denominators therefore differ and the two time points are not directly comparable. MSP intensity is reported as mean (SD). Regional pain case is defined as MSP intensity score ≥ 3 within the specific body region, and reported as n/N (%), where N denotes the number of participants with available data at each time point and varies by body region. A participant may be counted as a pain case in multiple body regions.

Table 6 Intention-to-treat analysis of general health, work ability, and burnout outcomes at baseline, 12 weeks, and 20 weeks by treatment group

	IPET+ERGO (n=41)			ERGO (n=42)			Between-group effect estimate (95% CI) Baseline vs. 20 weeks	P value
General health and work ability	Baseline	12 weeks	20 weeks	Baseline	12 weeks	20 weeks		
General overall health score, n (%)							1.36 (0.44 to 4.17)	0.594
Excellent	6 (14.6)	6/30 (20.0)	8/27 (29.6)	11 (27.5)	13/37 (35.1)	10/32 (31.2)		
Very good	22 (53.7)	16/30 (53.3)	12/27 (44.4)	18 (45.0)	17/37 (45.9)	14/32 (43.8)		
Good	13 (31.7)	8/30 (26.7)	7/27 (25.9)	11 (27.5)	6/37 (16.2)	8/32 (25.0)		
Fair	0 (0.0)	0/30 (0.0)	0/27 (0.0)	0 (0.0)	1/37 (2.7)	0/32 (0.0)		
Poor	0 (0.0)	0/30 (0.0)	0/27 (0.0)	0 (0.0)	0/37 (0.0)	0/32 (0.0)		
Work ability score, NRS 0-10, mean (SD/SE)	8.9 (1.0)	9.0 (0.2)	9.2 (0.2)	8.9 (1.1)	9.1 (0.2)	8.9 (0.2)	0.24 (-0.25 to 0.73)	0.337
Burnout								
Personal burnout score, range 0- 24, mean (SD/SE)	8.3 (3.3)	6.9 (0.4)	6.3 (0.5)	7.2 (3.3)	6.6 (0.4)	6.2 (0.4)	0.14 (-1.07 to 1.35)	0.816
Work-related burnout score, range 0-28, mean (SD/SE)	7.8 (4.7)	6.6 (0.5)	5.9 (0.5)	6.5 (3.6)	6.7 (0.5)	6.3 (0.5)	-0.39 (-1.86 to 1.08)	0.602

Observed baseline values are presented as mean (SD) for continuous outcomes and n (%) for categorical outcomes. The 12- and 20-week values for continuous outcomes are model-estimated marginal means (SE) from the mixed model. Follow-up values for categorical outcomes are observed n/N (%), where N denotes the number of participants with available data at each time point. Effect estimates represent the model-based between-group difference at 20 weeks. For ordinal outcomes, effect estimates are OR-based estimates from the corresponding model, and one overall 20-week between-group comparison is reported. P values are from model-based tests of between-group differences at 20 weeks. Higher work ability scores indicate better work ability. Higher burnout scores indicate higher burnout.

DISCUSSION

In this multicenter randomized trial among abdominal and pelvic surgeons, the addition of IPET to ERGO did not reduce worst MSP at 20 weeks compared with ERGO alone. The hypothesis of a synergistic, clinically relevant effect of IPET+ERGO over ERGO alone was therefore not supported. This finding contrasts with a body of evidence in which workplace-based, individually tailored IPET has demonstrated meaningful reductions in MSP across occupational groups [21], and in which strength training has been particularly effective for rehabilitation of work-related MSP [19].

Three explanations for the absent between-group effect warrant consideration. First, IPET as a concept may transfer poorly to a surgical population, whose MSP arises from prolonged static postures and high-precision micro-movements rather than from the gross physical loading seen in industrial and healthcare cohorts where IPET has previously been tested [Sjøgaard, 2023 #8325]. Second, the IPET dose received may have been too low to produce a measurable effect. Only 22% of IPET+ERGO participants met the pre-specified adherence threshold of minimum 70%, and the mean weekly training time was well below the prescribed 50 minutes. Third, ERGO acted as an active comparator rather than as a no-treatment control, and both groups reduced worst MSP from baseline by 1.4-1.6 NRS points, reductions that meet thresholds for minimum clinically meaningful improvement [Dworkin, 2008 #8422].

We consider the first explanation unlikely. The biological rationale for tailored strength and aerobic training in MSP rehabilitation does not depend on the type of physical loading, and surgical work, although low in gross load, involves precisely the static, repetitive and precision-demanding exposures, that IPET is designed to counteract. The remaining two explanations, insufficient dose under the chosen delivery model and a clinically meaningful improvement in the comparator group, may be the most plausible drivers of the null finding, and likely interact: pragmatic, app-only delivery in leisure time produced low adherence, while a meaningful ERGO response in both arms further reduced the contrast between groups.

A direct comparison with previous IPET trials is also complicated by differences in outcome assessment. Earlier IPET trials typically measured mean MSP across multiple body regions or focused on a single anatomical site [Dalager, 2023 #3514][Andersen, 2008 #3522], whereas the present trial used worst MSP in each participants' baseline most painful. This approach reflects the

logic of the IPET concept, as exercise is prescribed to the most affected region, but it limits direct comparison of effect sizes across trials.

Further, previous IPET trials provided structured workplace support, with exercise performed during working hours and some degree of supervision at least during the initial phase [21]. In the present trial, IPET was delivered via a mobile app, performed in leisure time, and left to the individual to initiate and sustain. This was an attempt to accommodate surgeon preferences and competing work schedules [26, 27], but it also meant that the conditions typically associated with adequate adherence were not in place. These differences in delivery context are likely central to understanding why adherence was low, as discussed below.

Adherence and intervention dose

Adherence to IPET was low. Only nine of 41 IPET+ERGO participants (22%) were classified as adherent, and at both 12 and 20 weeks, half of the IPET+ERGO participants reported doing less than 30 minutes per week. Most participants did therefore not receive a sufficient IPET “dose” to produce measurable changes in MSP, which likely reduced the contrast between groups.

This interpretation is consistent with previous IPET trials, in which pain reduction has followed a dose-response pattern, with adherence of 70% or above has been associated with reductions in mean pain intensity of up to 80% over a 12-week period [21, 22]. The ITT estimate in the present trial should therefore be interpreted as the effect of offering app-delivered IPET under pragmatic conditions, rather than the effect of receiving an adequate IPET dose. However, the per protocol analysis did not support this dose-response pattern seen in earlier work, but given the nine adherent participants, this analysis should be interpreted with caution.

Self-reported adherence captured weekly training duration, but not exercise compliance (i.e. load, progression, or whether the prescribed exercises were performed as intended), which in itself is an important determinant of pain reduction [49]. The app provided guidance on selecting the appropriate resistance band, but the extent to which participants followed this guidance is unknown. Providing access to the app and to elastic resistance bands is not equivalent to ensuring adequate training compliance, and even participants classified as adherent may have varied considerably in the actual IPET dose received.

Implementation burden

IPET was delivered via a mobile app and elastic resistance bands, with no formal introduction to the app or the prescribed exercises, besides in the brief IPET session at trial start. Although the app offered supportive features such as notifications, a knowledge bank, and a training community, access to these resources is not equivalent to receiving instruction and supervision. Previous IPET trials provided structured workplace support, including dedicated health ambassadors at the worksite to support implementation and sustain engagement [50, 51], and exercise performed during working hours with some degree of supervision at least in the initial phase [Dalager, 2015 #170]. Worksite-based training has been shown to be more effective than home-based training [52]. In the present trial, no such support was in place, and surgeons were expected to initiate and sustain training independently in their leisure time, an attempt to accommodate surgeon preferences and competing work schedules [Dalager, 2019 #7351], but one that removed the conditions typically associated with adequate adherence.

This does not necessarily imply that unsupervised or app-delivered exercise is ineffective. A study comparing supervised with unsupervised IPET among office workers found training compliance, MSP reduction, and muscle performance improvement, with average adherence ranging from 33 to 44% [39], and a meta-analysis of app-delivered exercise interventions of 4 to 12 weeks duration found a moderate effect on pain intensity [25]. However, other evidence suggests that digital support alone may be insufficient to improve adherence in chronic musculoskeletal conditions [53], and that app-delivered exercise tends to produce lower adherence than personally supervised exercise [54].

Surgeons are a highly time-constrained occupational group, and completing IPET in leisure time competes directly with personal and family commitments. Even when worksite exercise is offered on-site with organizational support, clinical staff may participate less than administrative staff [55], and this challenge is likely greater for surgeons. Without a structured introduction and without protected time, the combined behavioral demands of the trial - applying ergonomic principles in the OR, coordinating microbreaks with the OR team, and completing regular IPET - may simply have been too high [56].

ERGO uptake faced similar challenges. Only 22% of participants reported taking intraoperative microbreaks always or most of the time, despite the recommendation to do so at least every 60 minutes. Posters, QR codes, and a single oral presentation may raise awareness, but they may not be

sufficient to change team behavior in the OR. Microbreaks require coordination with the entire OR team, and consistent sustained practice depends on training, a supportive and psychologically safe team culture [57, 58], local facilitation [51], leadership support, and organizational structures that make ergonomic behavior part of routine surgical practice for all OR staff [56]. These conditions were not systematically established in this trial.

ERGO as an active comparator and within-group improvements

Both groups reduced worst MSP from baseline to 20 weeks by approximately 1.4 points in IPET+ERGO and 1.7 points in ERGO. Further, worst MSP in the past seven days was statistically significantly lower in the ERGO group at 20 weeks, consistent with this pattern. Both within-group reductions correspond to minimum clinically meaningful reductions in MSP [59], and may suggest that establishing ergonomic awareness, improving working postures, and supported recovery during surgery (microbreaks) may contribute to MSP reduction in both groups.

Improvements of a clinically meaningful magnitude in both groups inevitably narrow the between-group contrast, making it harder to detect an added effect of IPET. The trial design does not, however, allow the independent effect of ERGO to be isolated, and the existing evidence on ergonomic interventions for MSP among workers with physically demanding jobs is limited and conflicting [Sundstrup, 2020 #8330; Sweeney, 2021 #178; Koshy, 2020 #1635].

Personal and work-related burnout scores also decreased from baseline to 20 weeks in both groups, though without a statistically significant between-group difference. Whether this reflects a genuine effect of the ERGO components, e.g. microbreaks providing structured recovery during the working day or non-specific effects of trial participation cannot be determined from this design.

Strengths and limitations

A strength of this trial was the pragmatic multicenter design across nine surgical departments at five Danish hospitals, which increases the relevance of the findings to routine clinical settings. The use of a prespecified statistical analysis plan and blinded interpretation of the primary results reduces the risk of outcome reporting bias, and validated questionnaires were used for outcome assessment where available.

This trial has several limitations that should be considered. Because ERGO was delivered to both groups, the trial cannot isolate the independent effect of ERGO or estimate the effect of IPET compared with no intervention. This design was chosen because ERGO was considered an essential

and ethically appropriate component of any intervention targeting surgeon MSP. Adherence to both ERGO and IPET was self-reported, which may introduce measurement error, and exercise compliance was not recorded. Attrition at 20 weeks was high at 28%, which may have reduced statistical precision and introduced attrition bias. Two participants were retained despite not meeting eligibility criteria, though their inclusion in both arms limits any directional bias. given the low adherence to IPET, the ITT estimate primarily reflect the effect of offering app-delivered IPET under pragmatic conditions, rather than the effect of receiving a sufficient IPET dose. The primary outcome was defined as worst MSP intensity in each participant's most painful body region, which captures each participant's most relevant pain region and reflects the logic of the IPET concept. However, it also means that the analyzed body region differed between participants, so the findings reflect overall worst MSP rather than the effect of the intervention on a specific anatomical region. Finally, randomization blocks were not included in the statistical model, because block identifiers were not available in the required format. This may have introduced some additional uncertainty in the estimates, though the extent is unknown.

Implications

For surgical departments considering MSP interventions, the present trial suggests that providing exercise materials and app access alone is unlikely to be sufficient. Implementation was the central challenge. Future interventions targeting surgeon MSP may benefit from combining ergonomic and evidence-based exercise components with stronger organizational support, at least supervised initiation of IPET, training in team-based microbreak routines, local facilitation, and leadership involvement, as these appear to be necessary conditions for adequate uptake, adherence and exercise compliance. Including a no-treatment control arm in future trials would allow the independent effects of ERGO and IPET to be disentangled. The present trial is best understood as a test of a minimal-support, app-delivered IPET model under pragmatic conditions, not as a test of IPET as delivered in earlier studies with structured workplace support. The absence of a between-group effect therefore does not rule out that IPET may reduce MSP among surgeons when implemented with adequate support.

Table 7 Cut-points leading to prescription of IPET in the Intelligent Motion app

	Variable	Measurement	Description Model	Cut-Point/Group Allocation
Job profile			<i>How would you categorize the physical demands in your main job?</i>	
			(1) Mainly sedentary work that does not require physical exertion	1. Sedentary: moderate to high intensity aerobic training
			(2) Work largely performed while standing or walking	2. Standing/walking: high intensity interval aerobic training + function training
	Occupational exposure category	Self-report	(3) Standing or walking work with some lifting and/or carrying activities	3. + 4. Physically heavy: whole body muscle endurance training
			(4) Heavy or fast-paced work, which is strenuous	
Physical capacity profile			<i>How would you score your aerobic capacity compared to others of your own age and sex?</i>	
	Cardiovascular fitness	Self-report	Assessed on a 0–10 numerical rating scale (NRS) ranging from as poor to as good as possible	Responses below 5 (corresponding to average) lead to prescription of extra aerobic training
			<i>How would you score your strength capacity compared to others of your own age and sex?</i>	
	Muscle strength	Self-report	Assessed on a 0–10 NRS ranging from as weak to as strong as possible	Responses below 5 (corresponding to average) lead to prescription of extra all-round strength training
	Balance and function	Self-assessment	Self-assessed standing time on non-dominant leg with the arms crossed over the chest (hands on the shoulders). Three trials are given	If the individual loses balance before reaching 30s, functional training is prescribed

Health profile	Body mass index	Self-assessed self-report	or Assessed as an individual's weight in kilograms divided by the square of height in meters	A body mass index above 25 leads to the prescription of extra aerobic training
			<i>For how many days in total have you had (specific body part) pain during the last 3 months/7 days?</i> <i>If symptoms have been prevalent for one or more days, a follow up question is asked about average pain intensity:</i>	Any symptoms lead to prescription-specific strength training for the body part. If an individual has symptoms in more than two (tree) body parts, the pain intensity guides the prioritization
	Musculoskeletal disorders	Self-report	<i>Please indicate your level of (specific body part) pain (0-10 NRS) within the last 3 months/7 days</i>	

The text in italics represents the questions being asked in the app to design the IPET program. NRS: numerical rating scale.

LIST OF ABBREVIATIONS

ERGO	Good Ergonomic
IPET	Intelligent Physical Exercise Training
MSP	Musculoskeletal pain
NRS	Numerical rating scale
SAP	Statistical Analysis Plan
OR	Operating room
RAS	Robotic-assisted surgery
LAP	Laparoscopic surgery
OPEN	Open surgery
ITT	Intention-to-treat

REFERENCES

1. Wu L, Liu S, Lommen J, Pudwell J, Pelland L, Bougie O. Prevalence of musculoskeletal pain among gynecologic surgeons performing laparoscopic procedures: A systematic review and meta-analysis. *International Journal of Gynecology and Obstetrics*. 2023;161(1):151-8.
2. Gabrielson AA-O, Tanidir YA-O, Castellani DA-O, Ragoori DA-O, Jean LA-O, Corrales MA-O, et al. A Global Survey of Ergonomics Practice Patterns and Rates of Musculoskeletal Pain Among Urologists Performing Retrograde Intrarenal Surgery. (1557-900X (Electronic)).
3. Young RJ, Allen A, McIntire D, Robinson EF, Bougie O, Kho KA. Work Related Pain in Gynecologic Surgeons - A National Survey. *J Minim Invasive Gynecol*. 2025.
4. Dixon F, Vitish-Sharma P, Khanna A, Keeler BD. Work-related musculoskeletal pain and discomfort in laparoscopic surgeons: an international multispecialty survey. *Annals of the Royal College of Surgeons of England*. 2023;105(8):734-8.
5. Gutierrez-Diez MC, Benito-Gonzalez MA, Sancibrian R, Gandarillas-Gonzalez MA, Redondo-Figuero C, Manuel-Palazuelos JC. A study of the prevalence of musculoskeletal disorders in surgeons performing minimally invasive surgery. *Int J Occup Saf Ergon*. 2018;24(1):111-7.
6. Dalager T, Sogaard K, Boyle E, Jensen PT, Mogensen O. Surgery Is Physically Demanding and Associated With Multisite Musculoskeletal Pain: A Cross-Sectional Study. *J Surg Res*. 2019;240:30-9.
7. Epstein S, Sparer EH, Tran BN, Ruan QZ, Dennerlein JT, Singhal D, et al. Prevalence of Work-Related Musculoskeletal Disorders Among Surgeons and Interventionalists: A Systematic Review and Meta-analysis. *JAMA Surg*. 2018;153(2):e174947.
8. Seagull FJ. Disparities between industrial and surgical ergonomics. *Work* (Reading, Mass). 2012;41 Suppl 1:4669-72.
9. de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU. Luxembourg: European Agency for Safety and Health at Work; 2019.
10. Koshy K, Syed H, Luckiewicz A, Alsoof D, Koshy G, Harry L. Interventions to improve ergonomics in the operating theatre: A systematic review of ergonomics training and intra-operative microbreaks. *Annals of Medicine and Surgery*. 2020;55:135-42.
11. Park A, Lee G, Seagull FJ, Meenaghan N, Dexter D. Patients benefit while surgeons suffer: an impending epidemic. *J Am Coll Surg*. 2010;210(3):306-13.
12. Liang B, Qi L, Yang J, Cao Z, Zu X, Liu L, et al. Ergonomic Status of Laparoscopic Urologic Surgery: Survey Results from 241 Urologic Surgeons in China. *PloS one*. 2013;8(7):e70423-e.
13. Wauben LS, van Veelen MA, Gossot D, Goossens RH. Application of ergonomic guidelines during minimally invasive surgery: a questionnaire survey of 284 surgeons. *Surg Endosc*. 2006;20(8):1268-74.
14. Fransiak J, Ko E, Kidd J, Alvarez-Secord A, Bell M, Boggess J, et al. Physical Strain and Urgent Need for Ergonomic Training Among Gynecologic Oncologists who Perform Minimally Invasive Surgery. *Gynecologic oncology*. 2012;125(2):S190-S.

15. Pierce SM, Heiman AJ, Ricci JA. Evaluating the Current State of Ergonomics Education Offered to Students in US Medical Students. *Am Surg.* 2023;89(5):1798-806.
16. Cerier E, Hu A, Goldring A, Rho M, Kulkarni SA. Ergonomics Workshop Improves Musculoskeletal Symptoms in General Surgery Residents. *The Journal of surgical research.* 2022(k7b, 0376340).
17. Epstein S, Tran BN, Capone AC, Ruan QZ, Fukudome EY, Ricci JA, et al. The Current State of Surgical Ergonomics Education in U.S. Surgical Training: A Survey Study. *Annals of surgery.* 2019;269(4):778-84.
18. Sweeney K, Mackey M, Spurway J, Clarke J, Ginn K. The effectiveness of ergonomics interventions in reducing upper limb work-related musculoskeletal pain and dysfunction in sonographers, surgeons and dentists: a systematic review. *Ergonomics.* 2021;64(1):1-38.
19. Sundstrup E, Seeberg KGV, Bengtsen E, Andersen LL. A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work. *J Occup Rehabil.* 2020;30(4):588-612.
20. Sjøgaard G, Christensen JR, Justesen JB, Murray M, Dalager T, Fredslund GH, et al. Exercise is more than medicine: The working age population's well-being and productivity. *Journal of Sport and Health Science.* 2016;5(2):159-65.
21. Sjøgaard G, Mann S, Jensen JSD, Oestergaard AS, Dalager T. The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders. *Journal of Electromyography and Kinesiology.* 2021;61:102600.
22. Andersen LL, Kjær M, Sjøgaard K, Hansen L, Kryger AI, Sjøgaard G. Effect of two contrasting types of physical exercise on chronic neck muscle pain. *Arthritis and rheumatism.* 2008;59(1):84-91.
23. Lloyd GL, Chung ASJ, Steinberg S, Sawyer M, Williams DH, Overbey D. Is Your Career Hurting You? The Ergonomic Consequences of Surgery in 701 Urologists Worldwide. *J Endourol.* 2019;33(12):1037-42.
24. Sjøgaard G, Justesen JB, Murray M, Dalager T, Sjøgaard K. A conceptual model for worksite intelligent physical exercise training - IPET - intervention for decreasing life style health risk indicators among employees: a randomized controlled trial. *BMC Public Health.* 2014;14(1):652.
25. Thompson D, Rattu S, Tower J, Egerton T, Francis J, Merolli M. Mobile app use to support therapeutic exercise for musculoskeletal pain conditions may help improve pain intensity and self-reported physical function: a systematic review. *Journal of physiotherapy.* 2023;69(1):23-34.
26. Dalager T, Hojmark A, Jensen PT, Sogaard K, Andersen LN. Using an intervention mapping approach to develop prevention and rehabilitation strategies for musculoskeletal pain among surgeons. *BMC public health.* 2019;19(1):320.
27. Nielsen SG, Prins JL, Pedersen M, Saervoll CA, Molsted S. Little room for maneuvering: hospital managers' perspectives on integration of physical exercise during working hours. A qualitative investigation in a grounded theory design. *Journal of public health.* 2024.
28. StataCorp. *Stata Statistical Software: Release 17.* College Station, TX: StataCorp LLC; 2021.

29. Hopewell S, Chan AW, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 statement: updated guideline for reporting randomized trials. *Nat Med*. 2025;31(6):1776-83.
30. Christiansen HJ, Sandal LF, Mogensen O, Norasi H, Chrouser K, Hallbeck MS, et al. Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA). *Trials*. 2025;26(1):565.
31. Tetteh E, Wang T, Kim JY, Smith T, Norasi H, Van Straaten MG, et al. Optimizing ergonomics during open, laparoscopic, and robotic-assisted surgery: A review of surgical ergonomics literature and development of educational illustrations. *Am J Surg*. 2024;235:115551.
32. Mayo_Clinic. OR Stretch [Internet]: Mayo Clinic; [updated 2024. Available from: www.OrStretch.Mayoclinic.org.
33. Abdelall ES, Lowndes BR, Abdelrahman AM, Hawthorne HJ, Hallbeck MS. Mini Breaks, Many Benefits: Development and Pilot Testing of an Intraoperative Microbreak Stretch Web-Application for Surgeons. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 2018;62(1):1042-6.
34. Hallbeck MS, Lowndes BR, Bingener J, Abdelrahman AM, Yu D, Bartley A, et al. The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Appl Ergon*. 2017;60:334-41.
35. Dalager T, Sjöberg LM, Hansen AF, Sjøgaard G, Sjøgaard K. Afrapportering på ”Intelligent Motion implementering i dagligdagen”. https://www.sdu.dk/-/media/files/forskning/forskningsformidling/citizen_science/intelligent-motion-implementering-i-dagligdagen_fuld-rapport.pdf; University of Southern Denmark, Research unit of Physical Activity and Health in Working Life; 2024.
36. Dalager T, Justesen JB, Murray M, Boyle E, Sjøgaard G. Implementing intelligent physical exercise training at the workplace: health effects among office workers-a randomized controlled trial. *Eur J Appl Physiol*. 2016;116(7):1433-42.
37. Lange B, Toft P, Myburgh C, Sjøgaard G. Effect of Targeted Strength, Endurance, and Coordination Exercise on Neck and Shoulder Pain Among Fighter Pilots: A Randomized-controlled Trial. *The Clinical journal of pain*. 2013;29(1):50-9.
38. Gram B, Holtermann A, Sogaard K, Sjøgaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers--a randomized controlled intervention study. *Scand J Work Environ Health*. 2012;38(5):467-75.
39. Dalager T, Bredahl TG, Pedersen MT, Boyle E, Andersen LL, Sjøgaard G. Does training frequency and supervision affect compliance, performance and muscular health? A cluster randomized controlled trial. *Man Ther*. 2015;20(5):657-65.
40. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied ergonomics*. 1987;18(3):233-7.
41. Ware JE, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care*. 1996;34(3).
42. Kristensen TS, Borritz M, Villadsen E, Christensen KB. The Copenhagen Burnout Inventory: A new tool for the assessment of burnout. *Work and stress*. 2005;19(3):192-207.

43. Ilmarinen J. The Work Ability Index (WAI). *Occupational Medicine*. 2007;57(2):160-.
44. Grimby G, Börjesson M, Jonsdottir IH, Schnohr P, Thelle DS, Saltin B. The "Saltin-Grimby Physical Activity Level Scale" and its application to health research. *Scand J Med Sci Sports*. 2015;25 Suppl 4:119-25.
45. Strøyer J, Essendrop M, Jensen LD, Warming S, Avlund K, Schibye B. Validity and reliability of self-assessed physical fitness using visual analogue scales. *Percept Mot Skills*. 2007;104(2):519-33.
46. Statens Institut for Folkesundhed SU. Spørgeskema: Hvordan har du det? 2021 Odense (DK): Syddansk Universitet; 2021 [Available from: https://regionsyddanmark.dk/media/yytpvb01/sp%C3%B8rgeskema-sundhedsprofilen-2021.pdf?utm_source=chatgpt.com].
47. Sjøgaard G, Christensen JR, Justesen JB, Murray M, Dalager T, Fredslund GH, et al. Exercise is more than medicine: The working age population's well-being and productivity. (2213-2961 (Electronic)).
48. Broglio K. Randomization in Clinical Trials: Permuted Blocks and Stratification. *JAMA*. 2018;319(21):2223-4.
49. Dalager T, Welch A, O'Leary SP, Johnston V, Sjøgaard G. Clinically Relevant Decreases in Neck/Shoulder Pain Among Office Workers Are Associated With Strength Training Adherence and Exercise Compliance: Explorative Analyses From a Randomized Controlled Trial. *Physical therapy*. 2023;103(2):1.
50. Dalager T, Sjøgaard G, Justesen JB, Steele J. Intelligent Physical Exercise Training in a Workplace Setting Improves Muscle Strength and Musculoskeletal Pain: A Randomized Controlled Trial. *Biomed Res Int*. 2017;2017(2017):1-9.
51. Eskerod P, Justesen JB, Sjøgaard G. Enriching project organizations with formal change agents: Health promotion projects at the workplace. *International Journal of Managing Projects in Business*. 2017;10(3):578-99.
52. Jakobsen MD, Sundstrup E, Brandt M, Andersen LL. Effect of physical exercise on musculoskeletal pain in multiple body regions among healthcare workers: Secondary analysis of a cluster randomized controlled trial. *Musculoskeletal Science and Practice*. 2018;34:89-96.
53. Bunting JW, Withers TM, Heneghan NR, Greaves CJ. Digital interventions for promoting exercise adherence in chronic musculoskeletal pain: a systematic review and meta-analysis. *Physiotherapy*. 2021;111:23-30.
54. Martinsen L, Østerås N, Moseng T, Tveter AT. Adherence to in-person and app-based exercise for patients with hip or knee osteoarthritis; secondary analyses from a randomized controlled trial. *Rheumatology International*. 2025;45(9):208.
55. Pultz CJ, Lohse TM, Justesen JB, Særvoll CA, Møller SF, Lindegaard B, et al. Implementation of Intelligent Physical Exercise Training at a Danish Hospital—A Qualitative Study of Employees' Barriers and Facilitators for Participation. 2023.
56. Yazdani A, Wells R. Barriers for implementation of successful change to prevent musculoskeletal disorders and how to systematically address them. *Appl Ergon*. 2018;73:122-40.
57. Gretton-Watson P, Oakman J, Leggat SG. What is the nature, extent and impact of bullying in surgical settings? Insights of surgeons in Australia and Aotearoa New Zealand. *ANZ Journal of Surgery*. 2024;94(1-2):24-9.

58. Sutariya R, Kunamneni S, Zhang WW, Fay K, Al-Mansour M, Narula N. Surgeons' Experiences and Perspectives on Physical Ergonomics: A Need for Innovative Solutions. *Surgical innovation*. 2026.
59. Dworkin RH, Turk DC, Wyrwich KW, Beaton D, Cleeland CS, Farrar JT, et al. Interpreting the Clinical Importance of Treatment Outcomes in Chronic Pain Clinical Trials: IMMPACT Recommendations. *J Pain*. 2008;9(2):105-21.

Supplementary materials

Table 8 Baseline characteristics of complete-cases and non-complete cases

Demographic, work and health-related characteristics	Complete cases (n=56)	Non-complete cases (n=27)
Worst MSP intensity, NRS 0-10, mean (SD)	3.8 (2.0)	3.7 (1.8)
Pain-case, n (%)	43 (76.8%)	21 (77.8%)
Multisite pain, n (%)	51 (91.1%)	25 (92.6%)
Age, years, mean (SD)	49.7 (8.3)	45.9 (8.6)
Female sex, n (%)	34 (60.7%)	19 (70.4%)
BMI, kg/m ²	24.5 (3.4)	24.4 (3.1)
Surgical specialty, n (%)		
Gynecology	16 (28.6%)	6 (24.0%)
Urology	20 (35.7%)	10 (40.0%)
Colorectal surgery	19 (33.9%)	9 (36.0%)
Other	0 (0.0%)	0 (0.0%)
Weekly working hours, mean (SD)	41.2 (5.5)	39.3 (3.1)
Leisure-time physical activity level, n (%)		
Physically inactive	3 (5.4%)	2 (8.0%)
Some light physical activity	26 (46.4%)	13 (52.0%)
Regular physical activity and training	24 (42.9%)	10 (40.0%)
Regular hard physical training for competitive sports	3 (5.4%)	0 (0.0%)

Values are presented as mean (SD) or n (%). Complete-cases were defined as participants with complete primary outcome data at baseline, 12 weeks, and 20 weeks. Non-complete cases were randomized participants who did not meet this definition. Percentages are calculated among participants with available data for each variable.

Table 9 Baseline characteristics of IPET+ERGO participants by IPET adherence status

	Adherent (n= 9)	Non-adherent (n= 15)
Demographic, work and health-related characteristics		
Worst MSP intensity, NRS 0-10, mean (SD)	4.0 (2.1)	3.9 (2.0)
Pain-case, n (%)	7 (77.8)	11 (73.3)
Multisite pain, n (%)	9 (100.0)	14 (93.3)
Age, years, mean (SD)	53.0 (10.5)	48.0 (8.4)
Female sex, n (%)	5 (55.6)	10 (66.7)
BMI, kg/m²	25.7 (3.2)	25.6 (2.9)
Surgical specialty, n (%)		
Gynecology	2 (22.2)	2 (13.3)
Urology	4 (44.4)	7 (46.7)
Colorectal surgery	3 (33.3)	6 (40.0)
Other	0 (0.0)	0 (0.0)
Weekly working hours, mean (SD)	42.4 (7.8)	40.8 (6.4)
Leisure-time physical activity level, n (%)		
Physically inactive	0 (0.0)	1 (6.7)
Some light physical activity	5 (55.6)	9 (60.0)
Regular physical activity and training	4 (44.4)	5 (33.3)
Regular hard physical training for competitive sports	0 (0.0)	0 (0.0)

Values are presented as mean (SD) or n (%). Adherence to IPET was defined as completing $\geq 70\%$ of the prescribed Intelligent Motion sessions over the 20-week intervention period. Pain case was defined as a worst MSP intensity score ≥ 3 on a 0–10 numerical rating scale. Multisite pain was defined as MSP in ≥ 2 body regions.

APPENDIX 1

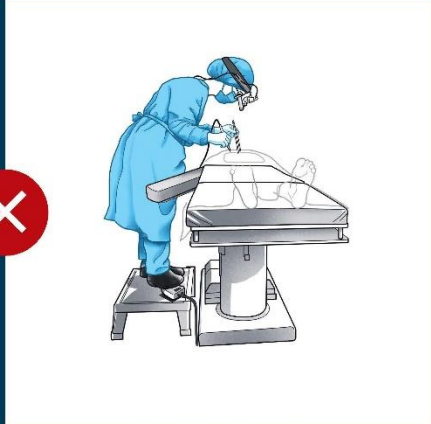
OPEN poster

GOOD ERGONOMICS

WORKING POSTURE - OPEN SURGERY



- Maintain neutral neck posture
Select light headlamp and high declination angle
- Maintain neutral torso posture
Engage deep trunk (pelvis) muscles
- Maintain pelvic girdle symmetry
Keep feet at hip width distance with weight evenly distributed
- Table height
Adjust to height of the tallest person, with steps for others
- Feet pedals
Place heel to foot flat, no with target position entry
- Tuck patient arms to avoid trunk twisting



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● Scan QR to know more about why your working posture is important



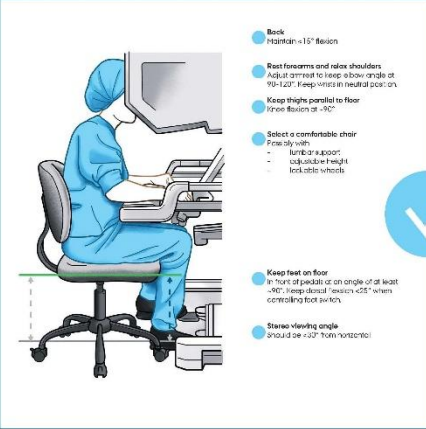
“Why your working posture is important” video



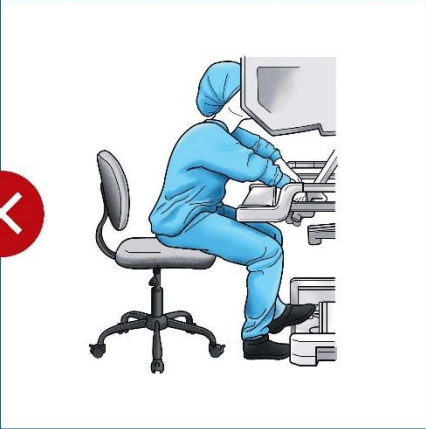
RAS poster

GOOD ERGONOMICS

WORKING POSTURE – ROBOT-ASSISTED SURGERY



- **Back**
Neutral $\pm 15^\circ$ flexion
- **Both forearms and upper shoulders**
Adjust screen to keep elbow angle at 90° – 120° . Keep wrists in neutral position.
- **Keep thighs parallel to floor**
Knee flexion at $\sim 90^\circ$
- **Select a comfortable chair**
Preferably with:
 - lumbar support
 - adjustable height
 - footrests/footrings
- **Keep feet on floor**
In front of pedals or at an angle of at least $\sim 90^\circ$. Keep distal femurs $< 25^\circ$ when controlling foot switch.
- **Stance viewing angle**
should be $\sim 20^\circ$ from horizontal



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● Scan QR to know more about why your working posture is important

 SDU

APPENDIX 2

Seated microbreak poster



Standing microbreak instructions



Seated microbreak instructions



“Why microbreaks are important” video



APPENDIX 3

GOOD ERGONOMICS

PhD-project Pain-free Surgeons



Why is GOOD ERGONOMICS important?

- Surgery involves prolonged static muscle activity, repetitive movements, and awkward working postures.
- These factors increase the risk of musculoskeletal pain.
- 8 out of 10 abdominal surgeons experience pain in multiple body sites.
- Work, leisure, and sleep are negatively affected.
- Knowledge of good ergonomic practice can help reduce the risk of musculoskeletal pain.
- Good Ergonomics is a set of ergonomic recommendations specifically developed for surgeons.
- Good Ergonomics represents phase 1 of the PhD project Pain-Free Surgeons.

How do I get started with ERGO?

Posters will soon be displayed in the operating rooms, and the project group will visit to kickstart the launch with a short presentation

Phase 1: Launch in the OR ERGO All OR team members Duration: 12 weeks	Phase 2: Randomized controlled trial INTELLIGENT PHYSICAL EXERCISE TRAINING (IPET) + ERGO vs. ERGO For surgeons Duration: 20 weeks
--	---

Project Pain-free Surgeons

Best regards,
Team Pain-free Surgeons

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CLINIC
  M

ERGO flyer



Tub of ERGO sweets

APPENDIX 4

Good Ergonomics Follow-up Questionnaire

Dear participant,

You are receiving this questionnaire because Good Ergonomics was launched in your department approximately 12 weeks ago (Phase 1). Good Ergonomics is part of the PainFree Surgeons project.

We would like to hear about your knowledge of Good Ergonomics and your experiences with it before we proceed to Phase 2. Your responses will contribute important knowledge about how we can prevent and address musculoskeletal pain among surgeons.

It is important for the quality of the study that you answer all questions, even if some seem similar. Please select the answer that best applies. The questionnaire takes approximately 10 minutes to complete.

All data and personal information are handled confidentially at Aarhus University, and all results will be reported at group level.

Contact Information

Please provide your email address

Please provide your mobile number

What is your primary place of work?

- ☐ Vejle Hospital
- ☐ Regionshospitalet Randers
- ☐ Regionshospitalet Gødstrup
- ☐ Odense University Hospital
- ☐ Aarhus University Hospital

What is your surgical specialty?

- ☐ Gynecology
- ☐ Colorectal surgery
- ☐ Urology
- ☐ Other

Musculoskeletal Pain

Musculoskeletal pain (MSP) is defined as pain or discomfort in muscles or joints.

In the past three months, how often have you experienced MSP when operating?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Most of the time
- ☐ Always
- ☐ Don't know

Please indicate where you primarily experience MSP (select all that apply)

- ☐ Neck
- ☐ Upper back
- ☐ Lower back
- ☐ Shoulders
- ☐ Elbow
- ☐ Wrist/hands
- ☐ Hip
- ☐ Knee
- ☐ Ankle/foot

Have you done anything to reduce your physical discomfort when operating?

- ☐ No
- ☐ Yes
- ☐ Don't know

What have you done to reduce your physical discomfort? (select all that apply)

- ☐ Taken microbreaks
- ☐ Changed working posture
- ☐ Refrained from operating for a period
- ☐ Taken pain medication
- ☐ Other: _____

Has MSP influenced your choice of surgical approach?

- ☐ No, never
- ☐ Yes, a few times
- ☐ Yes, most of the time
- ☐ Yes, every time
- ☐ Don't know

Knowledge of Good Ergonomics

Have you seen or heard about Good Ergonomics at your workplace?

- ☐ No
- ☐ Yes
- ☐ Don't know

Where have you seen or heard about Good Ergonomics? (select all that apply)

- ☐ Posters in the department
- ☐ Posters in the operating theatre or corridor
- ☐ Video
- ☐ Emails
- ☐ Departmental meeting
- ☐ Other: _____

Are you aware of other ergonomic initiatives in the operating theatre besides Good Ergonomics?

- ☐ No
- ☐ Yes
- ☐ Don't know

Which other ergonomic initiatives are you aware of?

To what extent have you used other ergonomic initiatives over the past three months?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Most of the time
- ☐ Always
- ☐ Don't know

What is your knowledge of ergonomic working postures when operating?

- ☐ Very good knowledge
- ☐ Good knowledge
- ☐ Some knowledge
- ☐ Very little knowledge
- ☐ No knowledge

What is your knowledge of intraoperative microbreaks?

- ☐ Very good knowledge
- ☐ Good knowledge
- ☐ Some knowledge
- ☐ Very little knowledge
- ☐ No knowledge

Which surgical modalities have you performed in the past three months? (select all that apply)

- ☐ Laparoscopy (or PNL endoscopy)
- ☐ Robotic surgery
- ☐ Open surgery
- ☐ Endoscopy
- ☐ None

Practice of Good Ergonomics - Working Postures

To what extent have you positioned yourself or equipment in the operating theatre to achieve an ergonomic working posture over the past three months?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Most of the time
- ☐ Always
- ☐ Don't know

What would make you more likely to apply ergonomic principles when operating? (select all that apply)

- ☐ More information about why it is important
- ☐ More training in how to apply it in practice
- ☐ More managerial support to prioritize it
- ☐ More time to adjust equipment/instruments
- ☐ Other: _____

Which ergonomic measures have you applied during laparoscopy? (select all that apply)

- ☐ Lowered shoulders and kept arm abduction below 30 degrees
- ☐ Kept forearm and upper arm in neutral position between supination and pronation
- ☐ Positioned the top of the monitor at eye level

- Positioned the monitor approximately one arm's length from the face
- Adjusted the operating table height to 70-80% of the distance from the floor to own elbow
- Maintained approximately 60 degrees angle between instruments
- Other: _____

Which ergonomic principles have you applied during robotic surgery? (select all that apply)

- Kept the upper body upright
- Used the armrest
- Chose a chair with back support
- Adjusted the height of the chair
- Kept feet on the floor when not using the foot pedal
- Kept viewing angle below 30 degrees
- Other: _____

Which ergonomic measures have you applied during open surgery? (select all that apply)

- Kept the neck in a neutral position
- Kept the upper body in a neutral position
- Kept the pelvis in a symmetrical position
- Adjusted the table to my height
- Placed the foot pedal beside the foot
- Positioned myself as close to the patient/surgical field as possible
- Other: _____

Please indicate your level of agreement with the following statements about Good Ergonomics - working postures:

Statement	Strongly agree	Agree	Partially agree	Disagree	Strongly disagree	Don't know
Posters with illustrations of ergonomic working postures make it easy to operate in an ergonomic position	☐	☐	☐	☐	☐	☐
I am always mindful of operating in an ergonomic working posture	☐	☐	☐	☐	☐	☐
Applying ergonomic principles is a good way to reduce or prevent MSP	☐	☐	☐	☐	☐	☐
Everyone in the operating theatre should be encouraged to follow ergonomic principles	☐	☐	☐	☐	☐	☐
The video about ergonomic principles has improved my understanding of how to prevent or address MSP	☐	☐	☐	☐	☐	☐

Practice of Good Ergonomics - Microbreaks

To what extent have you taken one or more intraoperative microbreaks with stretching over the past three months?

- Never
- Rarely
- Sometimes
- Most of the time
- Always
- Don't know

What would make you more likely to take microbreaks when operating? (select all that apply)

- ☐ More information about why it is important
- ☐ More training in how we do it in practice
- ☐ More support from colleagues (physicians)
- ☐ More support from others in the operating theatre
- ☐ More managerial support to prioritise it
- ☐ Other: _____

How did you become aware of taking a microbreak? (select all that apply)

- ☐ I remembered myself
- ☐ Physical discomfort in muscles or joints
- ☐ A scrub nurse gave a reminder
- ☐ A physician gave a reminder
- ☐ A timer
- ☐ Other: _____

How were the exercises performed? (select all that apply)

- ☐ Someone in the room read from the poster
- ☐ Someone in the room guided exercises from memory
- ☐ We scanned the QR code and listened to the audio file
- ☐ Other: _____

Please indicate your level of agreement with the following statements about Good Ergonomics - microbreaks:

Statement	Strongly agree	Agree	Partially agree	Disagree	Strongly disagree	Don't know
It is easy to remember to take microbreaks	☐	☐	☐	☐	☐	☐
It is easy to integrate microbreaks into my workflow	☐	☐	☐	☐	☐	☐
Microbreaks are a good way to reduce or prevent MSP	☐	☐	☐	☐	☐	☐
The video about microbreaks has improved my understanding of how to prevent or reduce MSP	☐	☐	☐	☐	☐	☐
Everyone in the operating theatre should be encouraged to take microbreaks	☐	☐	☐	☐	☐	☐

Comments

Thank you for your participation.

Helle Joon Christiansen, PhD student | hjchristiansen@clin.au.dk

APPENDIX 5

10.52

< Back

How would you best describe your daily work?

Sedentary
Work that does not require physical effort ☐

Standing/walking
Work that is primarily carried out standing or walking, but otherwise does not require physical effort ☒

Heavy work
Standing or walking work with some lifting or carrying ☐

Next

10.52

< Back

How would you describe your current cardiorespiratory fitness level?

The middle of the bar corresponds to an average cardiorespiratory fitness level compared to another person of the same gender and age.

Press the bar below

Worst Super

Next

10.52

< Back

How would you describe your current level of strength?

The middle of the bar corresponds to an average level of strength compared to another person of the same gender and age.

Press the bar below

Worst Super

Next

10.52

< Back

Were you able to stand on one leg for 30 seconds in 3 attempts or less?

Yes ☒

No ☐

Next

10.52

< Back

How many days in total have you experienced pain in lower back within the last 3 months?

Pain can be trouble and/or discomfort

1-7 days ☒

8-30 days ☐

More than 30 days ☐

Every day ☐

Next

10.52

< Back

Rate the intensity of your pain in the lower back within the last 3 months

Press the bar below

0 10

No pain Worst possible pain

Next

APPENDIX 6

PainFree Surgeons RCT - Baseline Questionnaire

You are invited to participate in a 20-week randomized controlled trial: Prevention and rehabilitation of musculoskeletal pain among surgeons using the Intelligent Motion app and Good Ergonomics. Participation requires completing this baseline questionnaire covering musculoskeletal pain, work, physical activity, health, and work ability. You will be asked to complete a similar questionnaire at 12 and 20 weeks.

Participation is voluntary. You may withdraw at any time by contacting hjchristiansen@clin.au.dk. All data are handled confidentially at Aarhus University. By proceeding you consent to processing of your personal data.

Participation

Do you wish to participate in a 20-week randomised controlled trial?

- ☐ No, I do not wish to participate.
- ☐ Yes, I wish to participate.

Inclusion and Exclusion Criteria

Do you perform surgery for a minimum of 4 hours in an average week?

- ☐ No
- ☐ Yes

Has your general practitioner advised against physical exercise training?

- ☐ No
- ☐ Yes

About You

Year of birth:

e.g. 1965

Sex:

- ☐ Female
- ☐ Male
- ☐ Prefer not to say

Height (cm):

Enter height in centimeters

Weight (kg):

Enter weight in kilograms

Musculoskeletal Pain - Upper Body

Please answer all questions, even if some appear similar. Select the category that best applies.

Neck

How many days in total have you experienced trouble (pain, discomfort or aching) in your neck during the past 3 months?

- ☐ 0 days
- ☐ 1-7 days
- ☐ 8-30 days
- ☐ More than 30 days, but not every day
- ☐ Every day

How many days has trouble in your neck prevented you from carrying out your daily activities (at work and at home) during the past 3 months?

- ☐ 0 days
- ☐ 1-7 days
- ☐ 8-30 days
- ☐ More than 30 days, but not every day

- Every day

Rate the severity of your trouble in your neck during the past 3 months:

(0 = no trouble; 10 = worst possible trouble)

Past 3 months	0	1	2	3	4	5	6	7	8	9	10
No trouble → Worst possible	○	○	○	○	○	○	○	○	○	○	○

Rate the severity of your trouble in your neck during the past 7 days:

(0 = no trouble; 10 = worst possible trouble)

Past 7 days	0	1	2	3	4	5	6	7	8	9	10
No trouble → Worst possible	○	○	○	○	○	○	○	○	○	○	○

The questions marked *** were repeated for Upper back, Lower back, Right shoulder, Left shoulder, Right elbow, Left elbow, Right wrist/hand, Left wrist/hand, Hip/thigh, Knee, Ankle/foot.

Pain Medication

How often have you used pain medication for musculoskeletal pain in any body region during the past 3 months?

- Daily
- 1 to several times per week
- 1 to several times per month
- Rarely or never

Work and Working Conditions

What is your surgical specialty?

- Gynecology
- Colorectal surgery
- Urology
- Other: _____

How many hours per week do you operate on average as primary surgeon?

Enter whole hours

How many hours per week do you operate on average as assisting surgeon?

Enter whole hours

How many hours per week do you work on average in total?

Enter whole hours

Physical Activity

The following questions concern physical activity in your leisure time and during transport (including to/from work).

In a typical week, how much time in total do you spend on moderate and vigorous physical activity that increases your breathing?

Examples: brisk walking, cycling, heavy gardening, jogging, recreational sports.

- Less than ½ hour (<30 min)
- ½ to 1½ hours (30-89 min)
- 1½ to 2½ hours (90-149 min)
- 2½ to 5 hours (150-299 min)
- 5 hours or more (≥300 min)

Of the time you indicated above, how much is spent on vigorous physical activity that leaves you too breathless to talk?

Examples: swimming, running, high-intensity cycling, hard strength training, team sports.

- Less than ½ hour (<30 min)
- ½ to 1 hour (30-59 min)
- 1 to 1½ hours (60-89 min)

- 1½ to 2½ hours (90-149 min)
- 2½ hours or more (≥150 min)

Thinking about the past year, which description best fits your leisure-time physical activity level? If it varies between summer and winter, try to find an average.

- 1. Sedentary - mostly inactive: reading, watching TV/film, using a computer, or other sedentary leisure activities
- 2. Some physical activity at least 4 hours per week - e.g. cycling or walking to work, skiing, gardening, fishing, table tennis, bowling
- 3. Regular physical activity and training (moderate): heavy gardening, jogging, swimming, gymnastics, tennis, badminton at least 2-3 hours per week
- 4. Regular hard physical training for competitive sports (vigorous): running, orienteering, skiing, swimming, football, handball several times per week

Physical Capacity Compared to Peers

Please rate your physical resources compared to peers of the same sex and age. The midpoint of each scale corresponds to average.

Cardiovascular fitness	0	1	2	3	4	5	6	7	8	9	10
<i>Poor → Good</i>	○	○	○	○	○	○	○	○	○	○	○

Muscle strength	0	1	2	3	4	5	6	7	8	9	10
<i>Weak → Strong</i>	○	○	○	○	○	○	○	○	○	○	○

Balance	0	1	2	3	4	5	6	7	8	9	10
<i>Poor → Good</i>	○	○	○	○	○	○	○	○	○	○	○

General Health (SF-12)

In general, how would you rate your health?

- Excellent
- Very good
- Good
- Fair
- Poor

Are you limited in these activities because of your health? If so, how much?

	Yes, very limited	Yes, somewhat limited	No, not limited at all
Moderate activities such as moving a table, vacuuming or cycling	○	○	○
Climbing several flights of stairs	○	○	○

During the past 4 weeks, how much of the time have you had the following problems with your work or daily activities due to your physical health?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
I accomplished less than I would have liked	○	○	○	○	○
I was limited in the kind of work or daily activities I could perform	○	○	○	○	○

During the past 4 weeks, how much of the time have you had the following problems due to emotional problems?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
I accomplished less than I would have liked	○	○	○	○	○

I performed work or other activities less carefully than usual	☐	☐	☐	☐	☐
--	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

During the past 4 weeks, how much did physical pain interfere with your normal work (including both work outside the home and housework)?

- ☐ Not at all
- ☐ A little
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

During the past 4 weeks, how much of the time...

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	☐	☐	☐	☐	☐	☐
Have you had a lot of energy?	☐	☐	☐	☐	☐	☐
Have you felt downhearted and blue?	☐	☐	☐	☐	☐	☐

During the past 4 weeks, how much of the time has your physical or emotional health interfered with your social activities (e.g. visiting friends or relatives)?

- ☐ All of the time
- ☐ Most of the time
- ☐ Some of the time
- ☐ A little of the time
- ☐ None of the time

Personal Burnout (CBI)

	Always	Often	Sometimes	Seldom	Never/almost never
How often do you feel tired?	☐	☐	☐	☐	☐
How often are you physically exhausted?	☐	☐	☐	☐	☐
How often are you emotionally exhausted?	☐	☐	☐	☐	☐
How often do you think: 'I can't take it anymore'?	☐	☐	☐	☐	☐
How often do you feel worn out?	☐	☐	☐	☐	☐
How often do you feel weak and susceptible to illness?	☐	☐	☐	☐	☐

Work-Related Burnout (CBI)

	To a very high degree	To a high degree	Somewhat	To a low degree	To a very low degree
Does your work drain you emotionally?	☐	☐	☐	☐	☐
Are you frustrated by your work?	☐	☐	☐	☐	☐
Do you feel burnt out because of your work?	☐	☐	☐	☐	☐

	Always	Often	Sometimes	Seldom	Never/almost never
Do you feel that every working hour is tiring for you?	☐	☐	☐	☐	☐
Do you feel exhausted in the morning at the thought of another day at work?	☐	☐	☐	☐	☐

Do you feel worn out at the end of your working day?	☐	☐	☐	☐	☐
--	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

Do you have energy to spend time with family and friends in your leisure time?

- ☐ Never/almost never
- ☐ Seldom
- ☐ Sometimes
- ☐ Often
- ☐ Always

Work Ability

Imagine that your work ability is worth 10 points when it is at its best.

Current work ability (0 = unable to work, 10 = best possible)	0	1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	---	---	----

Unable to work → Best possible ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

How do you rate your current work ability in relation to the physical demands of your job?

- ☐ Very good
- ☐ Good
- ☐ Moderate
- ☐ Poor
- ☐ Very poor

How do you rate your current work ability in relation to the mental demands of your job?

- ☐ Very good
- ☐ Good
- ☐ Moderate
- ☐ Poor
- ☐ Very poor

Has a doctor told you that you have any of the following conditions?

	No	Yes
Problems due to previous injury (e.g. head/neck, shoulder, or back injury)	☐	☐
Musculoskeletal disease (e.g. severe rheumatoid arthritis or arthrosis of neck, shoulder, or back)	☐	☐
Cardiovascular disease (e.g. hypertension, chest pain on exertion, heart failure)	☐	☐
Respiratory condition (e.g. allergy, asthma, recurrent respiratory infections, emphysema)	☐	☐
Depression or other mental illness	☐	☐

How many different doctor-diagnosed long-term conditions do you have in total?

- ☐ I have no doctor-diagnosed long-term conditions
- ☐ Number of doctor-diagnosed long-term conditions: _____

Do you have a condition that impairs your current work? (Mark all that apply)

- ☐ I have no conditions
- ☐ No, my condition does not impair or affect my work
- ☐ I am able to do my work, but it causes some symptoms
- ☐ I sometimes have to slow down my pace or change my methods
- ☐ I often have to slow down my pace or change my methods

- ☐ Due to my condition, I feel able to work only part-time
- ☐ I do not feel able to work

In the past 12 months, how many complete days have you taken off work due to illness?

- ☐ None
- ☐ 1-9 days
- ☐ 10-24 days
- ☐ 25-99 days
- ☐ 100-354 days

Thinking about your health, do you believe you will be able to perform your current job in 2 years?

- ☐ Unlikely
- ☐ Not certain
- ☐ Certain

Over the past 3 months, how often have you been able to...

	All of the time	Often	Sometimes	Rarely	Never
Enjoy ordinary daily activities?	☐	☐	☐	☐	☐
Feel active and engaged?	☐	☐	☐	☐	☐
Feel full of hope for the future?	☐	☐	☐	☐	☐

Thank you for your participation.

Helle Joon Christiansen, PhD student | hjchristiansen@clin.au.dk

Declaration of co-authorship concerning article for PhD dissertations

Full name of the PhD student: Helle Joon Christiansen

This declaration concerns the following article/manuscript:

Title:	Systematic review of applied ergonomics in pelvic and abdominal surgery on surgeon musculoskeletal health
Authors:	Helle Joon Christiansen, Emmanuel Tetteh, Susan Hallbeck, Kristin Chrouser, Ole Mogensen, Tina Dalager

The article/manuscript is: Published ☐ Accepted ☐ Submitted ☒ In preparation ☐

If published, state full reference:

If accepted or submitted, state journal: BMJ Open

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

Your contribution

Please rate (A-F) your contribution to the elements of this article/manuscript, **and** elaborate on your rating in the free text section below.

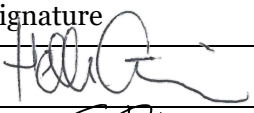
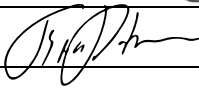
- A. Has essentially done all the work (>90%)
- B. Has done most of the work (67-90 %)
- C. Has contributed considerably (34-66 %)
- D. Has contributed (10-33 %)
- E. No or little contribution (<10%)
- F. N/A

Category of contribution	Extent (A-F)
The conception or design of the work:	A
<i>Free text description of PhD student's contribution (mandatory)</i> I took the lead in all aspects of study design, including defining the scope and objectives, developing the literature search and registered the protocol in PROSPERO prior to screening.	
The acquisition, analysis, or interpretation of data:	.B
<i>Free text description of PhD student's contribution (mandatory)</i> I performed all literature searches, led dual screening, data extraction and methodological assessment with co-authors.	
Drafting the manuscript:	A
<i>Free text description of PhD student's contribution (mandatory)</i> I wrote the full manuscript from initial draft to final version, incorporating structured feedback from all co-authors across multiple revision rounds	
Submission process including revisions:	A

Free text description of PhD student's contribution (mandatory)

I led two submission processes, including the current revision process involving a peer review response. Journal selection was a collaborative decision made with input from co-authors.

Signatures of first- and last author, and main supervisor

Date	Name	Signature
22/5-26	Helle Joon Christiansen	
22/5-26	Tina Dalager	

Date:

Signature of the PhD student

Declaration of co-authorship concerning article for PhD dissertations

Full name of the PhD student: Helle Joon Christiansen

This declaration concerns the following article/manuscript:

Title:	Prevention and rehabilitation of musculoskeletal pain among abdominal and pelvic surgeons with intelligent physical exercise training (IPET) and intraoperative ergonomic recommendations (ERGO): study protocol for a multicenter open-label randomized controlled trial in Denmark and North America (USA)
Authors:	Helle Joon Christiansen, Louise Fleng Sandal, Ole Mogensen, Hamid Norasi, Kristin Chrouser, M. Susan Hallbeck, Pernille Tine Jensen, Tina Dalager

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: <https://doi.org/10.1186/s13063-025-09178-x>

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

Your contribution

Please rate (A-F) your contribution to the elements of this article/manuscript, **and** elaborate on your rating in the free text section below.

- A. Has essentially done all the work (>90%)
- B. Has done most of the work (67-90 %)
- C. Has contributed considerably (34-66 %)
- D. Has contributed (10-33 %)
- E. No or little contribution (<10%)
- F. N/A

Category of contribution	Extent (A-F)
The conception or design of the work:	C
<i>Free text description of PhD student's contribution (mandatory)</i> The project was initiated within a pre-existing, externally funded framework (AMFF grant, awarded 2021). My contribution to design consisted of developing all operational and methodological details of the protocol, leading the multinational collaboration, writing the statistical analysis plan, and I led the full process from protocol development to trial registration and publication in Trials.	
The acquisition, analysis, or interpretation of data:	A
<i>Free text description of PhD student's contribution (mandatory)</i> As this is a protocol paper, I was responsible for all data acquisition planning, including design of the baseline and follow-up questionnaires in REDCap, and development of the pre-specified statistical analysis plan.	
Drafting the manuscript:	A

Free text description of PhD student's contribution (mandatory)

I drafted all sections of the protocol manuscript and revised them iteratively based on co-author feedback prior to submission.

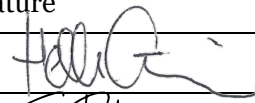
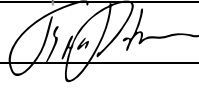
Submission process including revisions:

A

Free text description of PhD student's contribution (mandatory)

I managed the full submission processes, formatting to journal requirements, and responding to editor comments. Journal selection was a collaborative decision made with input from co-authors.

Signatures of first- and last author, and main supervisor

Date	Name	Signature
22/5-26	Helle Joon Christiansen	
22/5-26	Tina Dalager	

Date:

Signature of the PhD student

Declaration of co-authorship concerning article for PhD dissertations

Full name of the PhD student: Helle Joon Christiansen

This declaration concerns the following article/manuscript:

Title:	Awareness, Practice, and Perceptions Among Abdominal and Pelvic Surgeons Following an Ergonomic Educational Initiative: A Cross-Sectional Study
Authors:	Helle Joon Christiansen, Ole Mogensen, Kristin Chrouser, Susan Hallbeck, Tina Dalager

The article/manuscript is: Published ☐ Accepted ☐ Submitted ☒ In preparation ☐

If published, state full reference:

If accepted or submitted, state journal: Applied Ergonomics

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

Your contribution

Please rate (A-F) your contribution to the elements of this article/manuscript, **and** elaborate on your rating in the free text section below.

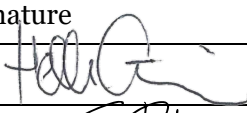
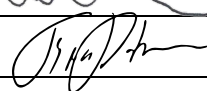
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- C. Has contributed considerably (34-66 %)
- D. Has contributed (10-33 %)
- E. No or little contribution (<10%)
- F. N/A

Category of contribution	Extent (A-F)
The conception or design of the work:	B
<i>Free text description of PhD student's contribution (mandatory)</i> The study was developed within the existing RCT framework, described in paper II. I led the design of the cross-sectional sub-study, including the formulation of research questions, development of the ERGO intervention and follow-up questionnaire, and selection of analytical methods, with input from co-authors.	
The acquisition, analysis, or interpretation of data:	A
<i>Free text description of PhD student's contribution (mandatory)</i> I carried out all aspects of data acquisition, including questionnaire distribution and collection across multiple hospital departments, performed the statistical analysis, and led the interpretation of results.	
Drafting the manuscript:	A
<i>Free text description of PhD student's contribution (mandatory)</i> I drafted all sections of the manuscript and revised them iteratively based on feedback from co-authors prior to submission.	
Submission process including revisions:	A

Free text description of PhD student's contribution (mandatory)

I managed the full submission process. Journal selection was a collaborative decision made with input from co-authors.

Signatures of first- and last author, and main supervisor

Date	Name	Signature
22/5-26	Helle Joon Christiansen	
22/5-26	Tina Dalager	

Date:

Signature of the PhD student

Declaration of co-authorship concerning article for PhD dissertations

Full name of the PhD student: Helle Joon Christiansen

This declaration concerns the following article/manuscript:

Title:	Intelligent Physical Exercise Training (IPET) and intraoperative ergonomic recommendations for musculoskeletal pain in surgeons: A Danish multicenter open-label randomized controlled trial
Authors:	Helle Joon Christiansen, Ole Mogensen, Kristin Chrouser, Susan Hallbeck, Tina Dalager

The article/manuscript is: Published ☐ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference:

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☐ Yes ☐ If yes, give details:

Your contribution

Please rate (A-F) your contribution to the elements of this article/manuscript, **and** elaborate on your rating in the free text section below.

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- D. Has contributed (10-33 %)
- E. No or little contribution (<10%)
- F. N/A

Category of contribution	Extent (A-F)
The conception or design of the work:	B
<i>Free text description of PhD student's contribution (mandatory)</i> The overall trial was conceived and funded prior to my appointment. Within this predefined framework, I led all operational aspects of the study design, including development of the intervention components, outcome measures, randomisation procedure, and the pre-specified statistical analysis plan, in collaboration with the supervisory team	
The acquisition, analysis, or interpretation of data:	B
<i>Free text description of PhD student's contribution (mandatory)</i> I was responsible for launch and recruitment across six of the nine departments at five Danish hospitals, including coordination of recruitment, managed the trial database, baseline and follow-up assessments, and data management in REDCap. I conducted all statistical analyses in Stata in accordance with the pre-specified analysis plan, with input from co-authors on the interpretation of results.	
Drafting the manuscript:	A

Free text description of PhD student's contribution (mandatory)

I drafted all sections of the manuscript, and made revisions iteratively based on co-author feedback.

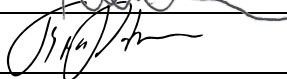
Submission process including revisions:

F

Free text description of PhD student's contribution (mandatory)

N/A

Signatures of first- and last author, and main supervisor

Date	Name	Signature
22/5-26	Helle Joon Christiansen	
22/5-26	Tin Dalager	

Date:

Signature of the PhD student