

Surgical Team Ergonomics During Robotic Versus Conventional Laparoscopic Surgery: A Prospective Observational Study

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Abstract

Background

Robotic surgery has been associated with improved ergonomics compared with conventional laparoscopy. However, most studies have focused on the console surgeon, and its impact on the entire surgical team remains poorly understood.

Methods

We conducted a cross-sectional study including robotic and conventional laparoscopic esophagogastric and colorectal procedures performed between September 2024 and March 2025. After each operation, primary surgeon and surgical assistants completed a structured questionnaire assessing musculoskeletal symptoms, posture, comfort, fatigue, and cognitive workload. Multivariable linear regression models adjusted for perceived procedural complexity and operative duration were performed for each ergonomic domain, with linear mixed-effects models used as sensitivity analyses.

Results

Ninety-two procedures were included. Questionnaires were completed by primary surgeons in 73 procedures (79.3% response rate) and by surgical assistants in 146 assessments. Compared with conventional laparoscopy, robotic surgery was independently associated with lower back, neck, shoulder, hand, and lower-limb pain, improved posture, greater comfort, and less physical fatigue among primary surgeons. Similar improvements were observed among surgical assistants. The results remained consistent in sensitivity analyses.

Conclusions

Robotic surgery was associated with a lower perceived ergonomic burden than conventional laparoscopy across different members of the surgical team. These findings suggest that the ergonomic benefits of robotic platforms extend beyond the console surgeon and support evaluating robotic surgery from a team-based ergonomic perspective.

INTRODUCTION

Surgical ergonomics is increasingly recognized as a key determinant of the sustainability of minimally invasive surgery. The ergonomic demand of an operation extends beyond the primary surgeon to the entire surgical team, which may be exposed to sustained static postures, repetitive movements, awkward positioning, visual and cognitive demands, time pressure, and the need to maintain high precision over prolonged periods. These demands may result in fatigue, discomfort, musculoskeletal

disorders (MSD), and impaired attention, potentially affecting professional well-being and team performance [1, 2]. Musculoskeletal disorders have been reported in 23%–100% of surgical personnel, depending on factors such as surgical specialty, approach, and operative duration [1]. This physical symptom is compounded by a demanding work environment characterized by complex procedures, time pressure, technological change, and frequent interruptions. Such emotional and cognitive demands may adversely affect psychomotor performance, communication, and decision-making [2, 3].

Technological advances have transformed minimally invasive surgery, particularly through the widespread adoption of laparoscopy and the more recent expansion of robotic platforms. Although laparoscopy offers well-established clinical benefits, its ergonomic limitations—including constrained instrument movement, non-neutral wrist positions, and suboptimal monitor positioning—have been associated with MSD rates of up to 90%–100% among laparoscopic surgeons [3–6]. Robotic surgery was developed, in part, to address these limitations by providing more natural instrument control, improved visualization, reduced physical demands, and the possibility of operating in a seated position. Accordingly, most studies have reported lower rates of physical discomfort with robotic surgery than with laparoscopic or open surgery [7–9]. However, substantial MSD have also been reported among robotic surgeons, with prevalence estimates ranging from 23% to 80% [10, 11].

The introduction of robotic surgery has substantially changed the interaction between the surgeon, the instruments, and the operative field [7, 9]. However, research has focused predominantly on the ergonomics of the surgeon seated at the robotic console. The impact of robotic surgery on the remainder of the surgical team has received considerably less attention. Assistants continue to work directly at the operating table and may therefore experience different postural, physical, and cognitive demands. Consequently, surgical ergonomics should be evaluated as a team-level phenomenon rather than solely from the perspective of the primary surgeon.

The primary aim of this study was to compare the perceived ergonomic symptoms of primary surgeons and surgical assistants during robotic and conventional laparoscopic procedures. Secondary aims were to assess differences in musculoskeletal disorders, fatigue, comfort, posture, and other physical and cognitive domains of the intraoperative experience, and to explore their associations with procedural and professional characteristics.

MATERIALS AND METHODS

Study design and population

We conducted an observational, analytical, cross-sectional study to assess the perceived ergonomic burden experienced by different members of the surgical team during complex procedures performed using robotic or conventional laparoscopic surgery. The study was conducted at a secondary-level hospital between September 2024 and March 2025 and included procedures performed by a surgical team specializing in bariatric and colorectal surgery.

The study was exploratory and no formal sample size calculation was performed. All consecutive procedures performed using the da Vinci robotic surgical platform or conventional laparoscopy during the study period were considered eligible. The primary surgeon and participating surgical assistants were invited to complete the assessment after each procedure. Surgeons and surgical assistants who routinely performed complex minimally invasive procedures and agreed to participate were eligible. Professionals who declined participation or did not routinely perform complex robotic or laparoscopic procedures were excluded.

A total of 92 surgical procedures were performed during the study period. Completed questionnaires were obtained from primary surgeons for 73 procedures, corresponding to a response rate of 79.3%. These responses were provided by 13 primary surgeons, some of whom contributed data from more than one procedure. Both the first and second assistant were invited to complete an independent questionnaire after each procedure.

The surgical approach was selected primarily according to robotic-system availability and routine surgical planning at the institution. The choice of surgical approach was not determined by the physical characteristics or MSD of the participating professional.

Because the allocation of robotic and laparoscopic procedures reflected routine clinical practice rather than random assignment, the study was designed to compare the ergonomic experience under real-world conditions. Procedure type was not included as a covariate in the primary models because of the limited sample size and the close relationship between procedure type and the choice of surgical platform, which could have resulted in model overfitting and unstable estimates.

Ergonomic assessment

At the end of each procedure, a structured questionnaire was administered to the primary surgeon and participating surgical assistants. The questionnaire was specifically developed for this study following a structured process based on previously published ergonomic questionnaires and studies evaluating musculoskeletal disorders, physical workload, and cognitive demands during minimally invasive surgery [6,8,12,13]. An initial version was drafted after a literature review and subsequently reviewed by surgeons with extensive experience in robotic and laparoscopic surgery to assess the clarity, relevance, comprehensiveness, and clinical applicability of each item. Although the questionnaire was not formally validated, its content was designed to capture the principal ergonomic domains reported in previous surgical ergonomics research.

The questionnaire comprised 32 items addressing professional characteristics, procedural characteristics, and the perceived ergonomic experience during surgery. Variables were organized into four domains: (1) procedural and professional characteristics; (2) physical workload and musculoskeletal disorders, including fatigue and pain in different anatomical regions; (3) comfort and posture and (4) visual, cognitive, and environmental demands, including fatigue, distractions, and stress (Supplementary S1). Questionnaires were completed anonymously immediately after each procedure.

Symptomatic and ergonomic variables were assessed using 1–10 scales. Visual analogue scales (VAS) ranging from 1 to 10 were selected because they are simple, intuitive and have been widely used in ergonomic research evaluating subjective symptoms. For the discomfort scale, higher scores indicated greater discomfort and therefore a worse ergonomic outcome. Procedural complexity and operative duration were included as measures of procedural workload.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Kolmogorov–Smirnov test and are presented as mean $\pm$ standard deviation (SD) or median and interquartile range (IQR), as appropriate. Variables measured on 1–10 visual analogue scales were analysed as continuous variables. Univariable comparisons were performed using Student's *t* test or the Mann–Whitney *U* test, and correlations were assessed using Pearson's or Spearman's coefficients, as appropriate.

For the multivariable analysis, a separate multiple linear regression model was fitted for each symptomatic or ergonomic domain measured on a 1–10 scale. The primary exposure variable was the surgical approach, with conventional laparoscopy used as the reference category and robotic surgery as the comparison category. All models were adjusted for procedural complexity and operative duration. Therefore, the β coefficient for robotic surgery represents the adjusted mean difference in the corresponding domain score compared with conventional laparoscopy.

Analyses were performed separately for primary surgeons and surgical assistants. Because of the available sample size, first- and second-assistant observations were analysed jointly. Assistant role was included as an additional fixed effect in the joint assistant analysis.

Collinearity between procedural complexity and operative duration was assessed using the variance inflation factor (VIF). VIF values were below 1.2, and both variables were therefore retained simultaneously in the models. Observations with missing data for any variable included in each model were excluded by listwise deletion.

The multiple linear regression models were prespecified as the primary analytical approach because they directly addressed the study objective of estimating adjusted associations between surgical approach and ergonomic outcomes. Linear mixed-effects models were prespecified as sensitivity analyses to evaluate the robustness of the findings after accounting for the correlation introduced by repeated observations from the same participant.

Regression coefficients (β), *p* values, and adjusted coefficients of determination (adjusted R^2) were reported for the multiple linear regression models. For the mixed-effects models, the consistency of the estimates and inferential conclusions was assessed in comparison with the primary analyses. A two-sided *p* value <0.05 was considered statistically significant.

Ethical Approval

Approval was granted by the Ethics Committee of University (approval number TFM.MPR.SEC.RPS.250224). All participants provided written informed consent. Data were anonymized before analysis and the study complied with the Declaration of Helsinki.

RESULTS

Study population and response rate

During the study period, 92 surgical procedures were performed by 13 different primary surgeons. Questionnaires were completed by primary surgeons after 73 procedures (79.3%). Among surgical assistants, 146 of the 184 expected questionnaires (79.3%) were completed by 22 assistants, including 73 first-assistant and 73 second-assistant assessments (Figure 1). The median age of primary surgeons was 45 years (interquartile range [IQR], 30), with a median surgical experience of 15 years (IQR, 15) and a median body mass index of 23 kg/m² (IQR, 8). Regular physical activity (≥ 3 days/week) was reported by 88% of primary surgeons. Only one surgeon did not perform on-call duties, and only one had received formal training in surgical ergonomics. The general characteristics of the professionals and procedures are summarized in Table 1.

Table 1. Characteristics of the study population and surgical procedures

Characteristic	Primary surgeon	Assistants
Total procedures, n	92	184
Completed questionnaires, n	73	146
Response distribution, %	80.4	79.3
Number of professionals, n	13	22
Age, years (mean $\pm$ SD)	44.2 $\pm$ 13.0	37.5 $\pm$ 13.4
Sex, n (%)		
Male	8 (61.5)	9 (40.9)
Female	5 (38.5)	13 (59.1)
Years of experience (mean $\pm$ SD)	19.1 $\pm$ 10.6*	19.1 $\pm$ 10.6*
Regular physical activity, n (%)	10 (76.9)	17 (81.0)

SD: standard deviation. Data in parenthesis are percentages.

* Ten of the thirteen primary surgeons also acted as assistants in procedures led by a colleague; years of experience was not recorded for assistants who had not yet reached attending status (residents in early training), which explains the high proportion of missing data for this variable among assistants.

Overall ergonomic profile of the surgical team

The overall ergonomic profile differed across surgical team roles (Table 2). Primary surgeons reported the highest prevalence of preoperative stress (75.7%), high procedural complexity (70.3%), concern about time (43.7%), and physical fatigue (41.9%). Musculoskeletal symptoms were most frequently reported in the back (21.8%), hands (19.0%), and neck (13.7%). Among first assistants, visual fatigue (38.4%), intraoperative time pressure (47.7%), back pain (26.1%), and shoulder pain (23.1%) were the most common findings. Second assistants reported the highest prevalence of visual fatigue (43.2%) and back pain (35.9%), whereas low comfort (40.7%) was also more frequently reported in this group. Overall, the distribution of ergonomic symptoms differed according to the role performed within the surgical team.

Table 2. Distribution of ergonomic symptoms and perceived workload according to surgical team role.

	MSDs in the primary surgeon	MSDs in the first assistant	MSDs in the second assistant
High complexity	52 (70.3)	41 (63)	60 (74.2)
High fatigue	31 (41.9)	20 (30.7)	26 (32.1)
Low comfort	23 (31.2)	20 (30.7)	33 (40.7)
Shoulder pain	9 (12.2)	15 (23.1)	16 (19.7)
Hand/finger pain	14 (19)	6 (9.2)	10 (12.3)
Back pain	16 (21.8)	17 (26.1)	29 (35.9)
Neck pain	10 (13.7)	12 (18.5)	12 (14.8)
Lower limb pain	5 (6.8)	9 (13.9)	5 (6.1)
Headache	10 (13.6)	5 (7.7)	8 (9.9)
Postural discomfort	16 (21.7)	4 (6.1)	14 (17.2)
Visual fatigue	12 (16.4)	25 (38.4)	35 (43.2)
Intraoperative distractions	12 (16.4)	21 (32.3)	18 (22.1)
Preoperative stress	56 (75.7)	12 (18.5)	11 (13.5)
Concern about time	32 (43.7)	31 (47.7)	10 (12.4)

MSD (musculoskeletal disorders) Data in parenthesis are percentages.

In exploratory analyses of individual characteristics, male primary surgeons reported higher scores in selected musculoskeletal and postural domains than female surgeons. In addition, the absence of

regular physical activity was associated with higher scores in several symptomatic domains. These exploratory analyses are summarized in Table 3.

Table 3. Exploratory univariable analyses comparing MSDs with surgical approach, surgeon's gender, and surgeon's physical activity level

	Surgical approach		Surgeon's gender		Exercise ≥3 days/week	
	Laparoscopic	Robotic	Male	Female	Yes	No
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Surgeon complexity	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.743		p=0.261		p=0.028	
Surgeon fatigue	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.151		p=0.182		p=0.000	
Surgeon comfort	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.007		p=0.259		p=0.017	
Surgeon shoulder pain	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.000		p=0.020		p=0.000	
Surgeon hand pain	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.008		p=0.022		p=0.001	
Surgeon back pain	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.000		p=0.005		p=0.001	
Surgeon neck pain	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.000		p=0.025		p=0.001	
Lower limb (surgeon)	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.002		p=0.229		p=0.000	
Surgeon headache	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.508		p=0.085		p=0.040	
Surgeon posture	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.000		p=0.007		p=0.001	

Surgeon visual fatigue	28 (37.84%)	46 (62.16%)	32 (43.24%)	42 (56.76)	67 (90.54%)	7 (9.46%)
	p=0.886		p=0.827		p=0.012	
Assistant 1 complexity	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.737		p=0.094		p=0.004	
Assistant 1 fatigue	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.111		p=0.075		p=0.010	
Assistant 1 comfort	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.005		p=0.984		p=0.402	
Assistant 1 shoulder pain	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.000		p=0.641		p=0.176	
Assistant 1 hand pain	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.002		p=0.646		p=0.199	
Assistant 1 back pain	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.073		p=0.009		p=0.281	
Assistant 1 neck pain	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.066		p=0.002		p=0.142	
Lower limb (assistant 1)	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.001		p=0.191		p=0.133	
Assistant 1 headache	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.235		p=0.085		p=0.045	
Assistant 1 posture	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)
	p=0.000		p=0.511		p=0.464	
Assistant 1 visual fatigue	25 (38.46%)	40 (61.54%)	28 (43.08%)	37 (56.92%)	55 (85.94%)	9 (14.06%)

	p=0.366		p=0.804		p=0.012	
Assistant 2 complexity	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.341		p=0.003		p=0.581	
Assistant 2 fatigue	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.004		p=0.949		p=0.570	
Assistant 2 comfort	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.771		p=0.258		p=0.001	
Assistant 2 shoulder pain	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.000		p=0.581		p=0.451	
Assistant 2 hand pain	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.002		p=0.419		p=0.175	
Assistant 2 back pain	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.003		p=0.664		p=0.515	
Assistant 2 neck pain	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.060		p=0.444		p=0.015	
Assistant 2 lower limb pain	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.000		p=0.839		p=0.320	
Assistant 2 headache	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.661		p=0.151		p=0.012	
Assistant 2 posture	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.000		p=0.393		p=0.270	
Assistant 2 visual fatigue	32 (39.51%)	49 (60.49%)	22 (27.16%)	59 (72.84%)	74 (91.36%)	7 (8.64%)
	p=0.564		p=0.474		p=0.138	

MSD (musculoskeletal disorders). Data in parenthesis are percentages. Values correspond to the score obtained using a visual analogue scale from 1 to 10. P-values below 0.05 were considered statistically significant.

Ergonomic differences according to surgical approach

In the multivariable analysis of primary surgeons, robotic surgery was independently associated with a lower symptomatic burden across most physical and postural domains after adjustment for procedural complexity and operative duration. All models were statistically significant, with adjusted R² values ranging from 0.163 for discomfort to 0.691 for back pain.

Robotic surgery was independently associated with significantly lower scores for back pain, neck pain, shoulder pain, hand pain, lower-limb symptoms, posture, discomfort, fatigue and distractions. The largest effect size was observed for back pain ($\beta = -3.64$), followed by neck pain ($\beta = -2.79$) and postural discomfort ($\beta = -2.44$) (Table 4). No statistically significant differences were observed between surgical approaches for headache ($p = 0.641$), visual fatigue ($p = 0.774$), or perceived stress ($p = 0.104$).

Table 4. Multivariate analysis for the lead surgeon.

Symptom	N	Adjusted R ²	β Robotic (vs Lap.)	p (Approach)	β Complexity (p)	β Time (p)	p model value
Physical Fatigue	73	0.668	-0.92	0.002	0.823 (<0.001)	0.138 (0.020)	<0.001
Comfort (discomfort)	73	0.163	-1.113	0.038	0.219 (0.154)	0.243 (0.023)	0.002
Shoulders	73	0.447	-2.134	<0.001	0.431 (<0.001)	0.06 (0.379)	<0.001
Hand	73	0.329	-1.375	0.003	0.339 (0.011)	0.283 (0.002)	<0.001
Back	73	0.691	-3.64	<0.001	0.67 (<0.001)	0.048 (0.480)	<0.001
Neck	73	0.524	-2.788	<0.001	0.416 (<0.001)	0.052 (0.457)	<0.001
Lower limbs	73	0.376	-1.557	<0.001	0.345 (<0.001)	0.035 (0.548)	<0.001
Headache	73	0.346	-0.197	0.641	0.611 (<0.001)	0.136 (0.108)	<0.001
Visual Fatigue	73	0.29	-0.127	0.774	0.15 (0.243)	0.401 (<0.001)	<0.001
Posture	73	0.399	-2.44	<0.001	-0.022 (0.854)	0.226 (0.006)	<0.001
Distractions	73	0.195	-1.285	0.005	0.434 (0.001)	0.007 (0.932)	<0.001
Stress	73	0.385	0.649	0.104	0.458 (<0.001)	0.254 (0.002)	<0.001

β Robotic represents the mean difference in symptom score for the robotic approach relative to the laparoscopic approach (reference), adjusted for perceived complexity and duration. Bold values indicate $p < 0.05$. The comfort scale was formulated as a degree of discomfort (1 = very comfortable; 10 = extremely uncomfortable), thus following the same direction as the other symptom scales (lower score = better outcome); a negative coefficient for the robotic approach therefore indicates greater comfort (less discomfort), consistent with the other domains.

In the joint assistant analysis, which included 146 observations, robotic surgery was independently associated with a lower ergonomic burden across most evaluated domains after adjustment for perceived procedural complexity and operative duration. Compared with conventional laparoscopy, assistants reported significantly lower physical fatigue, shoulder, hand, back, neck, and lower-limb pain, improved posture, and less discomfort. The strongest associations were observed for shoulder pain (β =

-2.45), posture ($\beta = -2.33$), and lower-limb pain ($\beta = -1.47$). No significant differences were found for headache, visual fatigue, distractions, or perceived stress (Table 5).

Table 5. Multivariate analysis for the assistants.

Symptom	N	Adjusted R ²	β Robotic (vs Lap.)	p (Approach)	β Complexity (p)	β Time (p)	p model value
Physical Fatigue	146	0.31	-1.284	<0.001	0.51 (<0.001)	0.138 (0.018)	<0.001
Comfort (discomfort)	146	0.071	-0.793	0.040	0.206 (0.048)	0.146 (0.047)	0.004
Shoulders	146	0.336	-2.45	<0.001	0.172 (0.054)	0.209 (0.001)	<0.001
Hand	146	0.182	-1.444	<0.001	0.196 (0.016)	0.108 (0.058)	<0.001
Back	146	0.168	-1.37	<0.001	0.234 (0.021)	0.216 (0.003)	<0.001
Neck	146	0.253	-0.857	0.009	0.187 (0.034)	0.356 (<0.001)	<0.001
Lower limbs	146	0.231	-1.468	<0.001	0.127 (0.078)	0.149 (0.004)	<0.001
Headache	146	0.118	-0.433	0.137	0.243 (0.002)	0.145 (0.010)	<0.001
Visual Fatigue	146	0.055	-0.049	0.882	0.262 (0.004)	0.066 (0.292)	0.011
Posture	146	0.247	-2.325	<0.001	0.159 (0.084)	0.045 (0.489)	<0.001
Distractions	146	0.106	0.104	0.765	0.186 (0.050)	0.238 (<0.001)	<0.001
Stress	146	0.221	-0.294	0.323	0.401 (<0.001)	0.186 (0.001)	<0.001

β Robotic represents the mean difference in symptom score for the robotic approach relative to the laparoscopic approach (reference), adjusted for perceived complexity and duration. Bold values indicate $p < 0.05$. The comfort scale was formulated as a degree of discomfort (1 = very comfortable; 10 = extremely uncomfortable), thus following the same direction as the other symptom scales (lower score = better outcome); a negative coefficient for the robotic approach therefore indicates greater comfort (less discomfort), consistent with the other domains.

Procedural complexity and operative duration were independently associated with several ergonomic outcomes in both primary surgeons and assistants. Overall, greater perceived complexity and longer operative duration were associated with higher symptom scores across multiple physical, postural, and cognitive domains, although the strength of these associations varied according to the specific outcome (Tables 4 and 5).

Sensitivity analysis using linear mixed-effects models

The results of the mixed-effects sensitivity analyses are shown in Supplementary S2 (Table 1 and 2).

Point estimates remained broadly similar to those obtained from the conventional regression models. Statistical significance was concordant in 22 of the 24 models evaluated: 11 of 12 models for primary surgeons and 11 of 12 models for assistants. Among primary surgeons, the principal associations between robotic surgery and musculoskeletal and postural domains were maintained. Among assistants, the associations with the main MSD and posture also remained stable, whereas the association with perceived discomfort was attenuated after accounting for clustering by professional. Overall, the sensitivity analysis supported the robustness of the principal findings.

DISCUSSION

The principal finding of this study was that robotic surgery was associated with a lower ergonomic burden than conventional laparoscopy across different members of the surgical team. This association extended beyond musculoskeletal disorders to include differences in comfort, posture, and physical fatigue. These findings suggest that the potential ergonomic benefit of robotic surgery may extend beyond the surgeon at the console and influence the intraoperative experience of the surgical team as a whole. To our knowledge, this is one of the first studies evaluating the ergonomic burden across the entire surgical team using adjusted analyses and sensitivity mixed-effects models.

MSD remain common among surgical professionals, with back pain being the most frequently reported symptom across the three roles evaluated in this study. This is consistent with previous reports describing a 20%–60% prevalence of low back pain among minimally invasive surgeons [11]. In our study, robotic surgery was associated with a lower musculoskeletal burden in both primary surgeons and assistants, consistent with previous evidence linking robotic systems to more neutral postures, reduced cervical torsion, and lower manual force requirements [12–14].

The inclusion of surgical assistants is a major strength of this study. Unlike the surgeon seated at the robotic console, assistants remain at the operating table and continue to face the traditional postural demands of minimally invasive surgery [15-16]. The role-specific distribution of symptoms—including hand and neck symptoms among primary surgeons and shoulder and lower-limb symptoms among assistants—suggests that ergonomic burden is not evenly distributed across the surgical team. Prolonged static postures, fixed operating-table height, and sustained instrument handling may particularly affect assistants during laparoscopic procedures [16-18]. Robotic surgery may reduce the

need to maintain awkward postures and hold instruments for prolonged periods. The postural discomfort observed among first assistants in 38.4% of procedures is consistent with the ergonomic demands previously described in the intraoperative setting [17–18].

The higher perceived physical fatigue reported in the laparoscopic group is also clinically relevant. The tendency of surgeons to continue working despite pain, as described by Szeto et al. [18], illustrates how ergonomic symptoms may become normalized and may not immediately result in reduced performance. However, repeated exposure to suboptimal physical demands may have cumulative consequences. Although our study did not directly assess surgical precision or intraoperative errors, reducing postural and physical strain may have implications for the long-term sustainability of surgical performance.

Procedure duration and complexity were also associated with several ergonomic domains. Previous studies have linked both factors to increased physical and cognitive fatigue [10,19]. In our cohort, however, duration was not consistently associated with MSD. This lack of a uniform association may reflect the influence of other individual and contextual factors and should therefore be interpreted as exploratory.

The sex-related findings should be interpreted cautiously. Whereas electromyographic studies have reported greater muscle activation and sensory and cognitive fatigue among women during laparoscopic procedures [20], male surgeons in our cohort reported a higher prevalence of selected musculoskeletal disorders. These differences may have been influenced by the limited sample size and by unmeasured factors such as anthropometry, height, or procedure type.

We found no consistent associations between age, body mass index, years of experience, and musculoskeletal disorders [6]. In contrast, regular physical activity was associated with a lower symptomatic burden. This finding is consistent with evidence linking core strength, flexibility, and muscular endurance to reduced postural fatigue and cumulative microtrauma [21,22]. Although causality cannot be inferred, these findings support the potential value of physical conditioning and ergonomic education as low-cost strategies to reduce MSD.

This study has several strengths. First, it evaluated multiple surgical roles, including primary surgeons and assistants, in a setting where professionals had experience with both robotic and laparoscopic surgery. Second, the multidimensional assessment extended beyond musculoskeletal pain to capture broader aspects of the intraoperative ergonomic experience. Importantly, the consistency between the primary regression models and the mixed-effects sensitivity analyses strengthens confidence that the observed associations were not substantially driven by repeated measurements contributed by the same professionals.

From an organizational perspective, these findings suggest that ergonomics should be considered part of the sustainability of minimally invasive surgery. The choice of surgical platform may have consequences beyond patient-centred outcomes, particularly as minimally invasive procedures become increasingly complex and prolonged. Assessing the ergonomic symptoms of the entire surgical team

may therefore complement the clinical and technical criteria traditionally used to compare surgical approaches.

Limitations

Several limitations should also be acknowledged. The relatively small number of participating professionals limited the precision of between-subject variance estimates in the mixed-effects models. Accordingly, multiple linear regression was retained as the primary analysis, while mixed-effects models were used as a sensitivity analysis and largely supported the main conclusions. Ergonomic symptoms were assessed using subjective scales without objective measures such as electromyography or biomechanical analysis. Residual confounding cannot be excluded because the surgical approach was not randomly assigned. In addition, the study-specific questionnaire had not undergone formal validation, although its development was informed by the existing literature and reviewed by surgeons experienced in minimally invasive surgery. Finally, the single-centre design limits the generalizability of the findings.

Conclusion

Robotic surgery was associated with a lower perceived ergonomic burden than conventional laparoscopy across different members of the surgical team, particularly in musculoskeletal, postural, and comfort-related domains. These findings support evaluating surgical ergonomics from a team-level perspective rather than focusing exclusively on the primary surgeon. Multicentre studies combining validated questionnaires with objective measures of postural and muscular load are warranted to confirm these findings.

Declarations

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Competing Interests

The authors declare that they have no conflict of interest. *The authors have no relevant financial or non-financial interests to disclose.*

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by RPS and JAGL. The first draft of the manuscript was written by MLGG and RPS and all authors commented on previous versions of the manuscript. Supervision by MLGG and VSA. All authors read and approved the final manuscript.

Ethical Approval

Approval was granted by the Ethics Committee of University (approval number TFM.MPR.SEC.RPS.250224). Data were anonymized before analysis and the study complied with the Declaration of Helsinki.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Artificial Intelligent

This manuscript has been translated with the assistance of artificial intelligence (ChatGPT)

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Figures

Figure 1. Flow diagram of participants and questionnaires (adapted from STROBE)

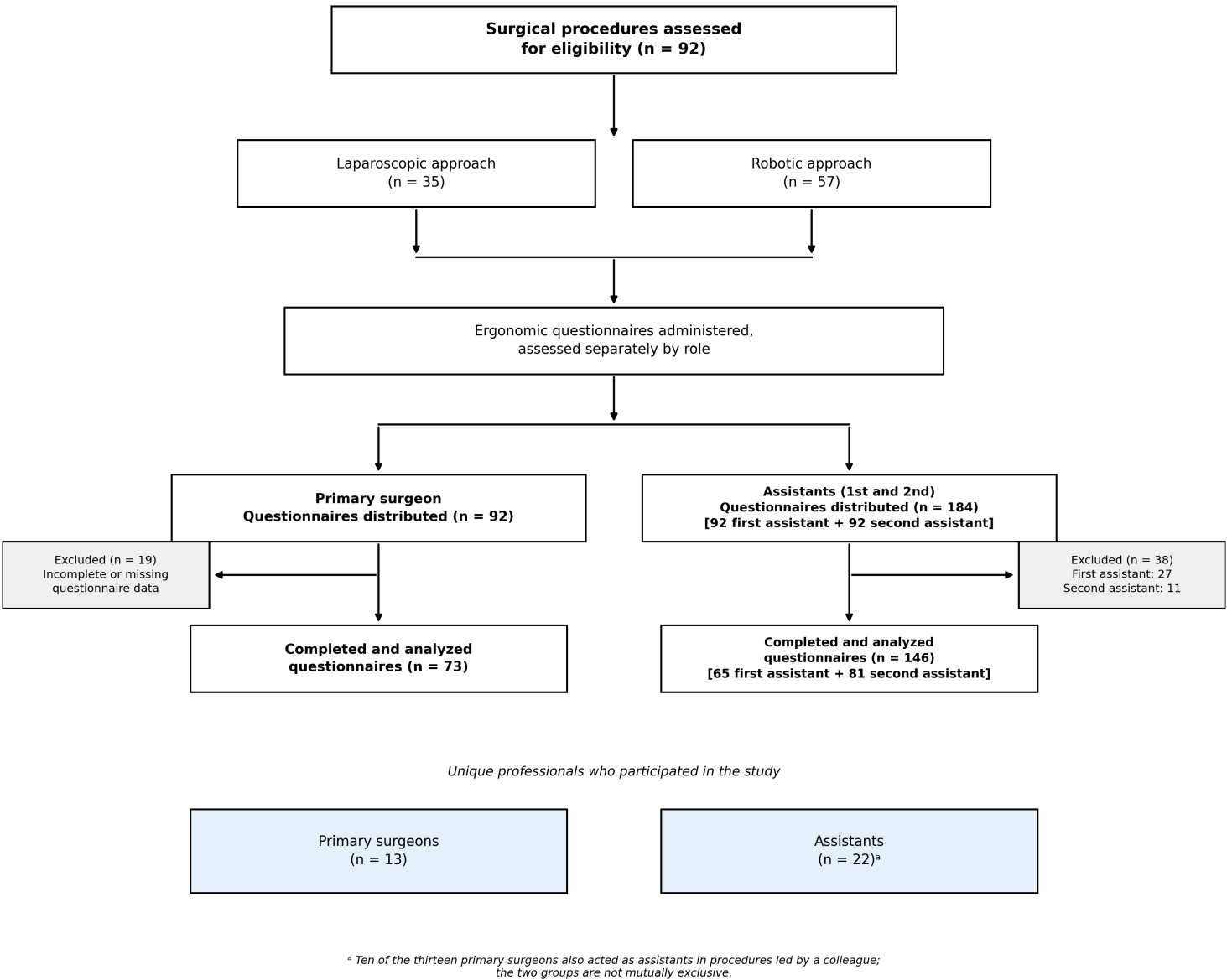


Figure 1

See image above for figure legend

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