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Review

Surgeon symptoms, strain, and selections: Systematic review and meta-analysis of surgical ergonomics

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ABSTRACT

Background: Many surgeons experience work-related pain and musculoskeletal symptoms; however, comprehensive reporting of surgeon ailments is lacking in the literature. We sought to evaluate surgeons' work-related symptoms, possible causes of these symptoms, and to report outcomes associated with those symptoms.
Materials and methods: Five major medical indices were queried for articles published between 1980 and 2014. Included articles evaluated musculoskeletal symptoms and ergonomic outcomes in surgeons. A meta-analysis using a fixed-effect model was used to report pooled results.
Results: Forty articles with 5152 surveyed surgeons were included. Sixty-eight percent of surgeons surveyed reported generalized pain. Site-specific pain included pain in the back (50%), neck (48%), and arm or shoulder (43%). Fatigue was reported by 71% of surgeons, numbness by 37%, and stiffness by 45%. Compared with surgeons performing open surgery, surgeons performing minimally invasive surgery (MIS) were significantly more likely to experience pain in the neck (OR 2.77 [95% CI 1.30–5.93]), arm or shoulder (OR 4.59 [2.19–9.61]), hands (OR 2.99 [1.33–6.71], and legs (OR 12.34 [5.43–28.06]) and experience higher odds of fatigue (8.09 [5.60–11.70]) and numbness (6.82 [1.75–26.65]). Operating exacerbated pain in 61% of surgeons, but only 29% sought treatment for their symptoms. We found no direct association between muscles strained and symptoms.
Conclusions: Most surgeons report work-related symptoms but are unlikely to seek medical attention. MIS surgeons are significantly more likely to experience musculoskeletal symptoms than surgeons performing open surgery. Symptoms experienced do not necessarily correlate with strain.

1. Introduction

Many surgeons have experienced a work-related injury such as cervical spinal stenosis, lumbar disc herniation, or carpal tunnel syndrome [1–5]. These injuries result in surgeons undergoing surgery themselves, taking leaves of absence, and even retiring earlier than planned [1,5]. Chronic pain, numbness, and fatigue also may occur from years of manual labor rather than as a result of a specific injury, while still potentially limiting overall work performance.

In the past, this problem was largely ignored, but now surgeons are actively seeking out ways to improve operating room ergonomics. Yet, efforts to improve surgical ergonomics severely lag behind those in other industrial fields. Therefore, a comprehensive report of surgeons' occupational symptoms and injuries may provide awareness of the ergonomic deficiencies in the surgical environment, and also may highlight potential consequences resulting from these deficiencies, ultimately promoting workplace improvements.

We performed a systematic review of the surgical literature on ergonomics, specifically evaluating work-related injuries or symptoms. Our primary goal was to evaluate the work-related symptoms experienced by surgeons. Our secondary goals were 1) to compare surgical approaches to determine the etiology of the symptoms; 2) to assess the consequences of the symptoms; and 3) to identify anatomic regions at highest risk of injury.

Abbreviations: EMG, electromyography; GEE, generalized estimating equations; MIS, minimally invasive surgery; MVIC, maximal voluntary isometric contraction; %MVIC, percentage of the maximal voluntary isometric contraction

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2. Methods

2.1. Systematic review

A systematic review was conducted to identify peer-reviewed research articles published between 1980 and 2014 that examined ergonomics in the operating room and surgeon-reported injuries and symptoms associated with various surgical procedures. Five major medical indices (Ovid MEDLINE, CINAHL, Embase, PsycINFO, and Scopus) were searched for words and phrases associated with ergonomics and work-related symptoms. Phrases that captured a symptom, injury, or intervention to alleviate pain and distress were used. The search terms for each database began with the following terms: *Surgery* OR *Operate* AND *Ergonomics.* When possible, the search criterion were then mapped to larger subject headings to expand search capabilities. The expanded key words were *surgical/surgeon pain*, *surgical/surgeon distress*, *discomfort*, *modification*, and *surgical/surgeon injury*. The search was limited to those articles with an available English translation of the full-text.

2.2. Study selection

Studies were excluded if their main purpose was to provide descriptive reports comparing brands of equipment or ergonomic efficiency of the design (speed of techniques or safety of equipment) rather than on injury risk reduction. Letters to the editor and case reports were also excluded. Finally, we limited our study to standard surgical procedures relatively generalizable to the surgical population, excluding papers reporting on developmental or highly specialized surgeries such as single-incision laparoscopic surgery, natural orifice surgery, and microvascular surgery. The surgeon population in the articles included in this study were general surgery, urology, gynecology, neurosurgery, orthopedic surgery, vascular surgery, cardiothoracic surgery, pediatric surgery, otolaryngology, plastic/hand surgery and ophthalmology. Original reports were included if they reported surgery-related symptoms or electromyography (EMG) outcomes in at least five participants performing open surgery, robotic or laparoscopic minimally invasive surgery (MIS), and endoscopic procedures.

2.3. Data abstraction and synthesis of symptom survey data

Titles and abstracts of articles identified using the criteria above were reviewed for inclusion by two authors (C.-C.H.S. and K.D.C.). These two authors evaluated each study independently, and when the authors did not agree on whether to include a study, the difference was resolved through input from a third author (J.N.C). Once articles were included, both authors performed data abstraction together for each article. Symptom survey data were predominantly reported as percentages of respondents experiencing symptoms or as scores on numerical scales (e.g., the Likert scale) and thus extracted using the actual percentages reported. If the results of a survey were not numerical or were reported in general terms, then the study was still listed in the review, but the data were not included in the analysis.

Lastly, survey data were stratified according to surgical approach (open surgery vs. MIS) when surgical approach data were available. In the MIS survey analysis, we included studies evaluating surgeons using laparoscopic and robotic approaches. An individual participant data (IPD) analysis was not performed.

2.4. EMG assessment

In order to identify anatomic regions at risk for injury, we included papers reporting EMG data as a numerical objective description of muscle strain. In ergonomics, EMG can be used to interpret muscle activation and fatigue and to analyze force and torque [6]. Describing the muscle force exerted during a procedure frequently involves measurement of the percentage of maximal voluntary isometric contraction (%MVIC) [6,7]. To our knowledge, no reference ranges for %MVIC are defined in the literature, and so an inferential statistical analysis of the EMG data was not performed. We reported which regional muscle groups were observed to exert the highest forces in terms of %MVIC.

2.5. Assessment of study quality

In an attempt to capture all studies of surgical ergonomics as it relates to work-related injury risk and symptoms in surgeons, we included in our literature review several articles whose data were not applicable to our meta-analysis. Some studies that we included surveyed participants after specific interventions or used discomfort/pain scales or injury risk scores that were not reported in terms translatable to our study. Study quality was scored according to 11 quality indicators previously published by Buckley et al. [8] Thirty manuscripts were considered higher quality studies by scoring 7 points or higher (range 4–9). Response rate was the primary endpoint when determining the completeness of the data and an adequate response rate was considered ≥60%. Those with high response rates were low-participant studies (overall range 7%–100%). Due to the number of manuscripts with inadequate response rates (16), the completeness of symptom and injury data may be biased in that those who have experienced work-related injury may be more likely to answer surveys on this topic. Conversely, a low response rate may not capture the actual extent of work-related injury.

2.6. Statistical analysis

We conducted a meta-analysis using a fixed-effect model to assess the surgeons' work-related physical burden. We considered all observations in each study to be repeated measures data and assumed a logit link function for binary outcomes. All seven pain symptoms (i.e., overall pain, neck pain, back pain, arm pain, hand pain, leg pain, and eye strain), three physical discomfort questions (i.e., numbness, stiffness, and fatigue), and three outcomes (i.e., pain influences the type of surgery performed, surgery exacerbates pain, and sought treatment for pain) were clustered for each study and were assumed to be equally correlated. A fixed-effect model of individual participant data to assess the surgeons' work-related physical burden was conducted for the meta-analysis. Generalized estimating equations method (GEE) of the fixed-effect model was used to estimate probabilities and 95% confidence intervals (CIs) for the surgeons' reported physical burden in terms of binary responses.

An exchangeable correlation structure was used to account for within-study correlation.

After analyzing the combined data, we also analyzed the symptom outcomes by two surgical approach subgroups: MIS and open surgery. Only studies separating data according to surgical approach were included in this subset analysis.

All reported *P* values were two-sided, and a *P* value of less than 0.05 was considered statistically significant. All analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC).

3. Results

3.1. Selected studies

We identified 984 articles, of which 882 were excluded based on content (Fig. 1). Ninety-five articles were then examined in detail. An additional 62 studies were excluded on the basis of the inclusion and exclusion criteria, resulting in 40 studies for our final analysis (Fig. 1). Twenty-one observational studies included only survey data [1,5,9–26], 10 studies evaluated muscle strain using EMG [27–36], three studies incorporated both EMG analysis and survey data [37–39], and six

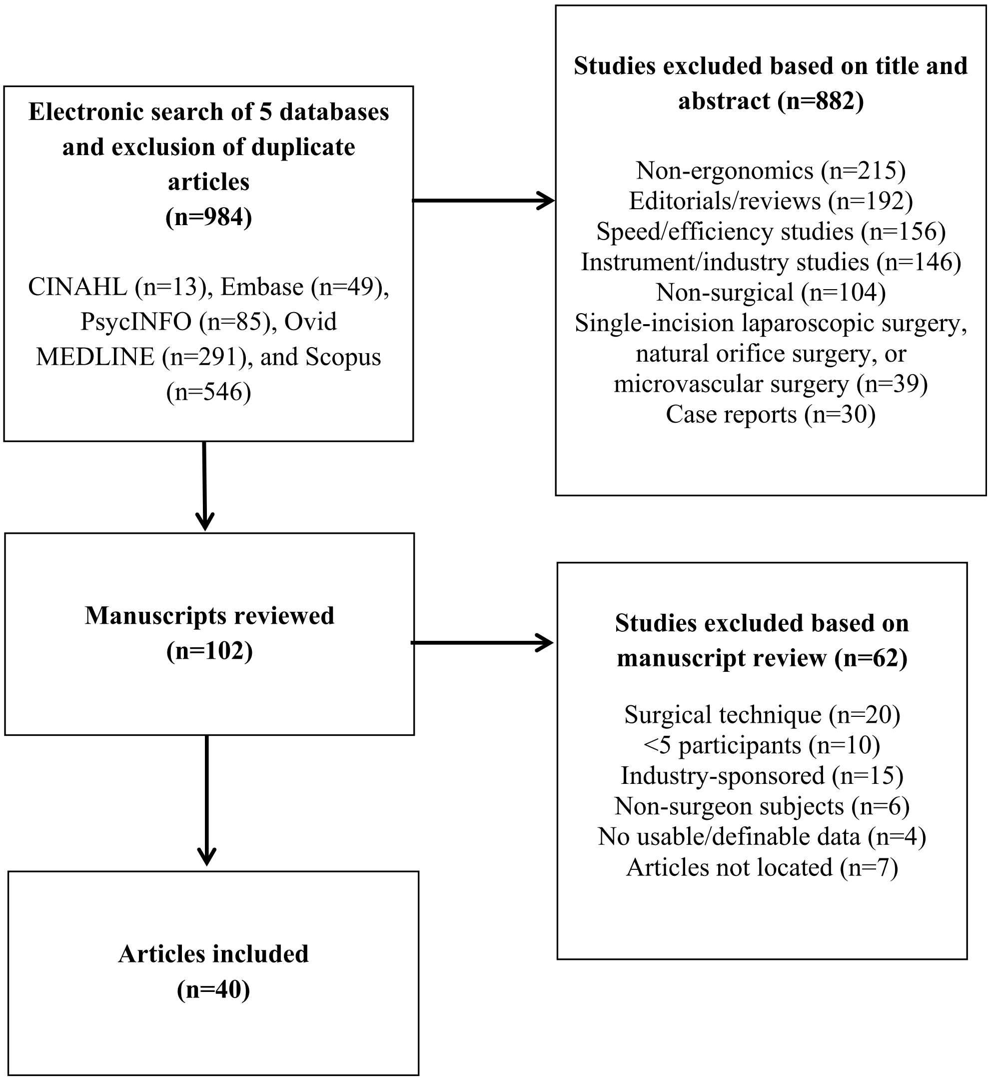

Fig. 1. Flow diagram for surgical ergonomics systematic review and meta-analysis.

studies used other tools such as pain scales and strain indices [1,40–45]. Of these only one study was a randomized case control design [28] while all other studies were non-randomized.

3.2. Aggregated survey data

Twenty-four studies surveyed 5152 surgeons with the majority of studies reporting at least four outcomes of interest (Table 1). Results from our meta-analysis are illustrated in Fig. 2. When asked about specific symptoms, 68% of the surgeons surveyed reported generalized pain, 71% experienced fatigue from operating, 37% attributed numbness to operating (generalized or site specific) and 45% reported stiffness after operating. Surgeons predominantly reported that they felt pain in the back (50%), neck (48%), and arm or shoulder (43%). Pain was also noted at lower frequencies in the eyes, hands, and legs (Fig. 2).

3.3. MIS vs. open surgery survey data

Eighteen of the survey manuscripts reported results of symptoms induced by MIS [5,9,13,14,16–19,21,23–26,37–39,46,47] versus 9 of the manuscripts reporting results from open procedures [10,13–15,21,22,39,46,47]. When stratifying according to surgical approach (MIS vs. open surgery), generalized pain was noted in 69% of MIS surgeons and 60% of surgeons performing open procedures (Table 2). Fatigue was considerably more common in those performing MIS versus open procedures (83% vs. 37%); numbness and stiffness were also more common in MIS surgeons than in open surgeons. The prevalence of back, neck, and arm or shoulder pain was similar between MIS surgeons and the surveyed surgeons overall (54%, 55%, and 53%, respectively); however, surgeons performing open procedures reported pain less frequently in those sites (37%, 31%, and 19%, respectively).

Additional analysis demonstrated that while overall pain was not statistically different between MIS and open groups, surgeons performing MIS were significantly more likely to experience pain in the neck (OR 2.77 [1.30–5.93]), arm or shoulder (OR 4.59 [2.19–9.61]), hands (OR 2.99 [1.33–6.71], and legs (OR 12.34 [5.43–28.06]) (Fig. 3). MIS surgeons also experienced substantially higher odds of fatigue (OR 8.09 [5.60–11.70]) and numbness (OR 6.82 [1.75–26.65]).

Only 3 articles surveyed surgeons performing robotic surgery [20,21,46]. Plerhoples et al. [20] reported results from the largest number of robotic surgeons (n = 837) while the other two groups did not specify the number of surgeons performing robotic versus laparoscopic surgery. A subset meta-analysis comparing symptoms in surgeons performing robotic versus laparoscopic versus open surgery would likely be heavily weighted based on results from a single paper, and therefore this was not performed. However, individual analysis showed overall pain in 23% to 53% of surgeons. Neck pain was present in 35%, back pain 21%, arm and shoulder pain 8%, and hand pain 28%. Plerhoples [20] also reported that only 3% of robotic surgeons noted that operating exacerbated their pain.

Table 1
Surgeon work-related symptoms reported on various published surveys.

First Author, Year of Publication	No. of Participants	Overall Pain N (%)	Neck Pain N (%)	Back Pain N (%)	Arm Pain N (%)	Hand Pain N (%)	Leg Pain N (%)	Eye Pain N (%)	Numbness N (%)	Stiffness N (%)	Fatigue N (%)	Pain Influences Type of Surgery N (%)	Surgery Exacer-bates Pain N (%)	Sought Treatment for Pain N (%)
Albayrak, 2007	7												2 (29)	
Bagrodia, 2009	106	46 (43)	23 (22)	23 (22)								27 (25)	39 (37)	
Berguer, 1999	149		77 (52)		82 (55)	70 (47)			51 (34)	92 (62)				
Berguer, 2004	726	145 (20)												
Cass, 2014	128	127 (99)	95 (74)	99 (77)	102 (80)	90 (70)	69 (54)	51 (40)	59 (46)	102 (80)	105 (82)			6 (5)
Cavanagh, 2012	100	62 (62)	37 (37)	35 (35)	35 (35)	12 (12)	2 (2)	35 (35)	17 (17)	30 (30)	37 (37)		62 (62)	35 (35)
Davis, 2013	140	62 (44)	14 (10)	27 (19)	10 (7)	35 (25)								24 (17)
Davis, 2014	260	104 (40)	49 (19)	96 (37)	23 (9)	57 (22)	18 (7)					91 (35)	172 (66)	127 (49)
Esposito, 2013	23	16 (70)		12 (52)	12 (52)							3 (13)	13 (57)	9 (37)
Forst, 2006	285					91 (32)						20 (7)	29 (10)	
Hemal, 2001	204		20 (10)	18 (9)	31 (15)	27 (13)	14 (7)	37 (18)	27 (13)	20 (10)				
Indramohan, 2012	50		13 (26)											
Kaya, 2008	40		29 (73)	23 (58)			15 (38)	10 (25)						
Liang, 2013	241		140 (58)	128 (53)	81 (34)	73 (30)	52 (22)							
Miller, 2012	61	61 (100)	56 (92)	53 (87)	35 (57)	22 (36)	23 (38)						61 (100)	
Park, 2010	317	273 (86)										95 (30)	184 (58)	266 (84)
Plerhoples, 2012	1215	838 (69)	510 (42)	486 (40)	231 (19)	170 (14)	85 (7)	158 (13)				365 (30)	838 (69)	207 (17)
Santos-Carreras, 2012	49	42 (86)	19 (39)	18 (37)	13 (27)	12 (25)								
Soueid, 2010	77	62 (81)	30 (39)	36 (47)		24 (31)						33 (43)	64 (83)	22 (29)
Sutton, 2014	314											201 (64)		15 (5)
Szeto, 2009	135	108 (80)	112 (83)	92 (68)	78 (58)							11 (8)	92 (68)	27 (20)
Szeto, 2010	25	21 (84)	5 (20)											
Wauben, 2006	284		222 (78)	219 (77)	219 (77)						250 (88)		219 (77)	
Welcker, 2012	216		177 (82)	180 (83)	165 (76)				157 (73)		167 (77)			
Total (n = 24)	5152	3362	3480	3279	3205	2909	2249	1687	797	581	728	2732	2870	2709
Pooled report		1967 (68.55)	1628 (47.71)	1545 (49.90)	1117 (42.85)	683 (29.71)	278 (221.38)	291 (26.01)	311 (36.70)	244 (45.29)	559 (71.36)	846 (29.22)	1775 (60.92)	738 (29.83)

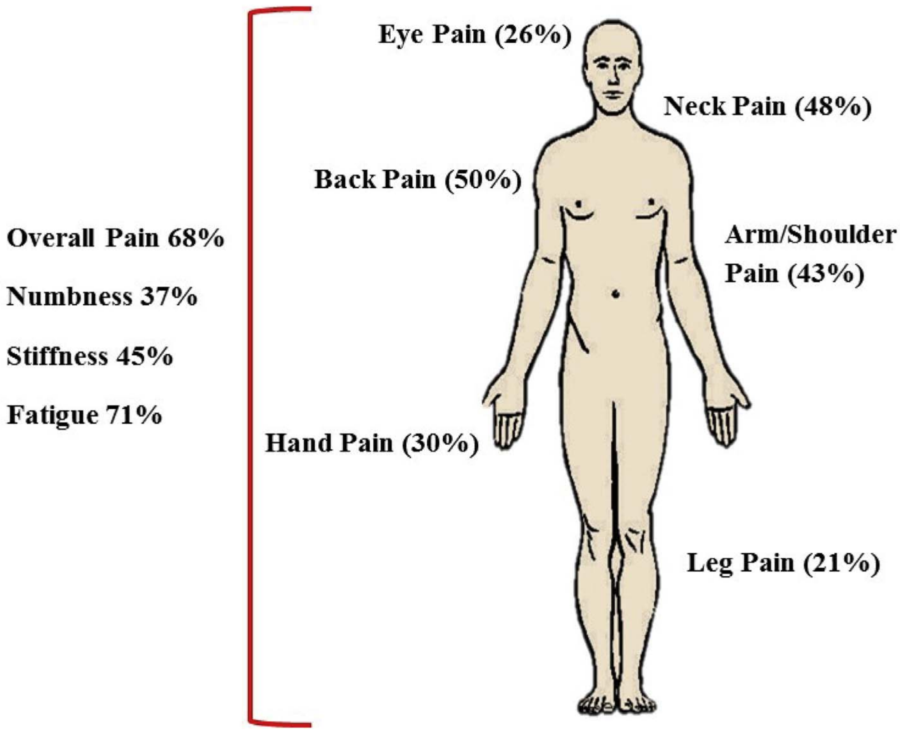

Fig. 2. Frequency of work-related site-specific symptoms in surveyed surgeons.

Table 2
Surgeons' work-related symptoms stratified by surgical approach.

Symptom	Surgeon-Reported Numbers			Fixed-Effects Model Outcomes		
	No. of Studies	No. of Surgeons with Symptom	Total No. of Surgeons	Percentage of Surgeons with Symptom	95% Confidence Interval	
MIS (laparoscopic and robotic)						
Overall pain	9	1242	2760	69.39	48.66	84.43
Back pain	11	1249	2606	53.69	38.08	68.62
Neck pain	13	1448	2780	55.22	40.75	68.86
Arm/shoulder pain	11	1085	2632	52.98	39.67	65.88
Hand pain	7	497	1974	34.99	23.24	48.90
Leg pain	6	303	1816	27.95	16.77	42.76
Eye pain	4	333	1514	26.41	19.10	35.30
Numbness	4	291	624	42.91	25.31	62.51
Stiffness	3	211	408	51.47	22.84	79.17
Fatigue	3	522	628	82.60	76.69	87.26
Open surgery						
Overall pain	7	628	1448	59.74	46.86	71.41
Back pain	7	688	1496	37.30	25.69	50.58
Neck pain	8	627	1548	30.86	21.52	42.07
Arm/shoulder pain	5	185	1313	19.37	12.16	29.43
Hand pain	5	136	1367	15.07	9.08	23.99
Leg pain	2	5	173	2.88	1.75	4.69
Eye pain	3	138	1241	17.64	7.76	35.30
Numbness	2	19	173	10.12	3.66	24.99
Stiffness	2	34	173	17.96	6.47	40.95
Fatigue	1	37	100	37.00	–	–

MIS = minimally invasive surgery.

Survey participants included a broad range of surgeons but larger studies did not report results according to surgical subspecialty or specific procedures. Therefore, separate analyses comparing symptoms by subspecialty or type of surgery were not performed.

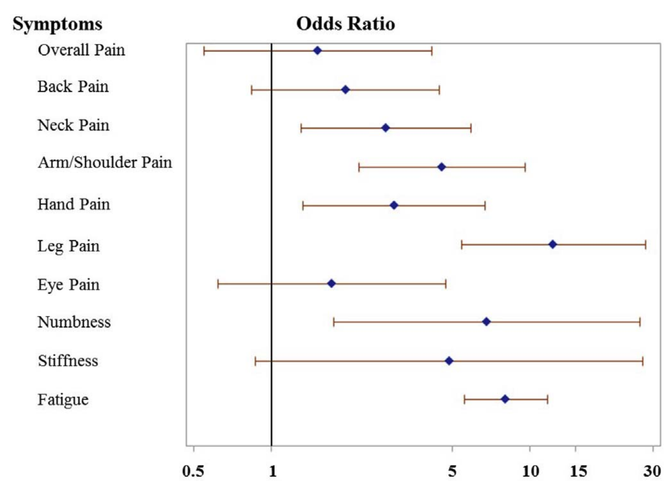

Fig. 3. Forest plot representing results of the meta-analysis of odds ratios for work-related symptoms experienced by surgeons who performed minimally invasive surgery vs. those who performed open surgery.

3.4. Consequences of surgeon symptoms

Several studies surveyed surgeons about the effects of their pain. Overall, 61% of those questioned said that they felt that operating exacerbated their pain (Fig. 4). MIS surgeons and open surgeons did not differ significantly on this measure (Fig. 4). Less than one-third of surgeons (overall 29%, MIS 27%, and open 26%) sought treatment for their symptoms, and about 30% said that they took their own physical symptoms into account when recommending a surgical approach for their patients (Fig. 4). Neither of these outcomes was significantly different between MIS surgeons and open surgeons.

3.5. Anatomic regions at risk/EMG results

The highest EMG recordings were noted in the hand/thumb with measurements as high as 95% MVIC (Table 3). One study measured

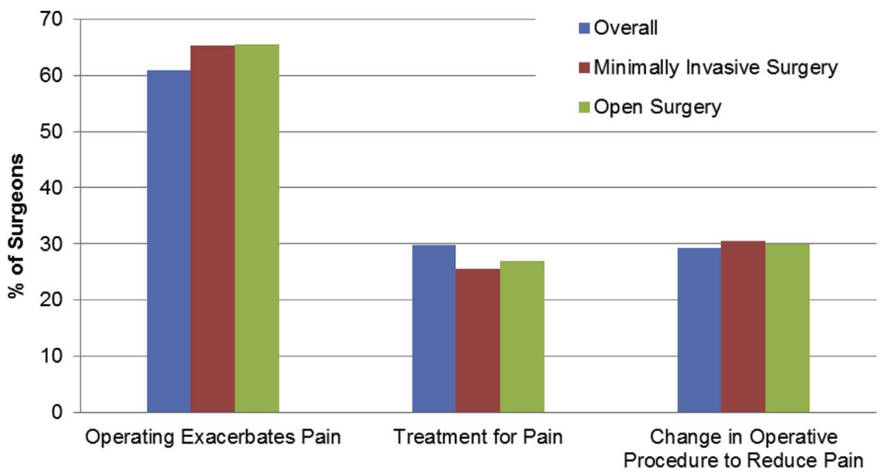

Fig. 4. Surgeons' opinions about and reactions to work-related symptoms stratified by surgical approach.

lower-extremity exertion and reported forces of up to 65% MVIC which was similar to the exertion of the forearm, which ranged from 32% MVIC to 64% MVIC. The lowest values for muscle exertion were noted in the back (18% MVIC to 36% MVIC) and shoulder (10% MVIC to 26% MVIC).

4. Discussion

To our knowledge, this is the first comprehensive systematic review of the surgical ergonomics literature on work-related musculoskeletal symptoms in surgeons. From these data, we found that a substantial number of surgeons worldwide suffer from work-related musculoskeletal ailments that often are exacerbated as those surgeons continue to operate. Surgeons using minimally invasive techniques had significantly higher odds of neck pain, upper and lower extremity pain, numbness, and fatigue than surgeons performing open surgery. Only 30% of surgeons said that they would take their musculoskeletal symptoms into account when considering an operative approach. These data would suggest that as the field of surgery focuses much of its effort on minimally invasive approaches, the consequence of compromising our surgical ergonomics is that the physical well-being of surgeons who perform MIS may continue to decline. A caveat to this prediction is that three studies in our review [20,21,46] demonstrated lower incidences of injury and symptoms in surgeons using robotic approaches. The field of robotic surgery is rapidly growing and perhaps as robotic procedures become more routine, future ergonomic studies might demonstrate lower incidences of surgery-related musculoskeletal symptoms in the surgeons performing robotic surgeries.

Of particular interest, this meta-analysis demonstrates that while the areas with the highest frequencies of reported pain are the back, neck, and shoulder, the muscle groups that undergo the most strain according to EMG analysis are the hand, lower extremities, and forearm. Therefore, we were not able to correlate surgeon pain symptoms with the anatomic sites presumed to be most at risk by EMG strain measurements. Similarly, Ruhe et al. [48] noted that the recorded EMG forces were results of voluntary active movements and did not necessarily reflect exertions made involuntarily in static conditions. Bedi et al. [49] explained that while dynamic factors are associated with mechanical hip pain, static overload stresses while in a standing position are also associated with mechanical hip pain. Our results, along with those of Ruhe and Bedi et al., suggest that a substantial amount of the discomfort experienced by surgeons is a result of a chronic process, as our bodies work against static forces, eventually leading to musculoskeletal symptoms and injuries.

Several groups included in this study have attempted to reduce the static forces incurred by implementing a variety of ergonomic interventions (monitor height, anti-fatigue mats, etc.) in the operating room. Most of these are not widely implemented in current surgical practice for numerous reasons. Seagull [50] summarizes these reasons, noting that the anatomy of the human body does not allow for redesign to optimize our work environment; each patient is unique, making surgical ergonomics difficult to standardize; surgeons are working with time constraints and often forgo breaks; surgeons concentrate on the procedure and frequently will not consider making ergonomic adjustments while operating; and finally, surgical instruments are subject to strict regulatory requirements that constrain optimal ergonomic designs. The culture of surgery has historically been self-sacrificing which is demonstrated by our meta-analysis findings that although most surgeons noted some type of work-related musculoskeletal symptom, less than 30% of them sought out medical treatment for these symptoms. A lack of awareness among surgeons of current ergonomic recommendations may also contribute to the delay in use of ergonomic

Table 3
Electromyographic analysis of surgeons' muscle groups during performance of various surgical tasks.

First Author, Year of Publication	No. of Participants	Country	%MVIC						
			Neck	Back	Shoulder	Upper Arm	Forearm	Hand/Thumb	Lower Extremity
Albayrak, 2007	1	Netherlands	**44**	**24**	–	–	–	–	**65**
Berguer, 1998	9	USA	–	–	–	–	**61**	**95**	–
Berguer, 1999	9	USA	–	–	–	–	**64**	**55**	–
Berguer, 1999	6	USA	–	–	–	–	–	**22**	–
Berguer, 1999	27	USA	–	–	–	–	**58**	–	–
Berguer, 2002	21	USA	–	**19**	**22**	–	–	**89**	–
Berguer, 2003	21	USA	–	–	**26**	–	**32**	–	–
Hubert, 2013	11	France	–	**36**	–	–	–	–	–
Szeto, 2010	11	China	**41**	**18**	**10**	–	–	–	–

%MVIC = percentage of maximum voluntary isometric contraction; - = not reported.

interventions since our meta-analysis found that 59%–99% of surgeons were unaware of the ergonomic recommendations of their own institutions, and none had received mandatory ergonomic training [17,19,25,26]. Perhaps as we promote awareness, surgeons will be more conscious of their operating room environment and future ergonomic studies will help identify interventions that might reduce our symptoms and risks of injury.

There are a few limitations to our study. First, most of the surveys evaluating MIS and open surgeons allowed individuals to answer questions for both surgical approaches rather than limiting answers to one approach or the other. The number of participants responding multiple times was frequently not reported. While performing the meta-analysis, we used the reported percentages to calculate from the total number of participants and when the responses were summed, the result was greater than the original total number of participants. Adjustment for this discrepancy may reduce the overall rates of musculoskeletal symptoms surgeons experience and diminish the consequences of these symptoms. Second, we were not able to standardize the EMG measurements among the trials because no reference range was available to quantify the meaning of the reported %MVICs. Therefore, the EMG data reported in this review can be used as only a conceptual basis for future studies.

5. Conclusions

This systematic review and meta-analysis summarizes musculoskeletal symptoms experienced by surgeons as a result of current operating room ergonomics. We found that most surgeons suffer from work-related symptoms, such as generalized pain; pain in the back, neck, and shoulder; and fatigue. MIS surgeons are significantly more likely to experience musculoskeletal symptoms than those performing open surgery. Surgeons believe that the act of performing surgery exacerbates their pain; however, while they may reconsider the surgical approach, they are unlikely to seek medical attention for their ailments. We also found that EMG studies do not necessarily predict at-risk anatomic sites of injury or symptoms since the areas of pain experienced by surgeons do not correlate with the muscle groups exerting the most force during an operation. Surgeons' symptoms may be due to chronic and repetitive processes in which pressure from static forces cause musculoskeletal strain and ultimately injury. While many interventions are available to improve surgical ergonomics, surgeons have yet to implement them for several reasons, including lack of education. Now is the time to perform additional research to improve the ergonomic environment of our operating rooms and to promote awareness and prevention of these injuries.

Ethical approval

n/a – systematic review/meta-analysis.

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Author contribution

All authors contributed to this study. Stucky, Cromwell and Voss participated in the study design, data collections, data analysis and writing. Ms. Chiang performed the data analysis. Drs. Woodman, Lee and Cormier also participated in the study design, editing and writing processes.

Conflicts of interest

None.

Research registration unique identifying number (UIN)

researchregistry3289.

Guarantor

Chee-Chee H. Stucky, MD, Janice N. Cormier, MD, MPH.

Disclosures

None of the authors have any financial conflicts of interest to disclose.

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