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High Prevalence of Work-related Musculoskeletal Disorders and Limited Evidence-based Ergonomics in Orthopaedic Surgery: A Systematic Review

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Abstract

Background The Centers for Disease Control defines work-related musculoskeletal disorders as disorders of the nerves, muscles, tendons, joints, spinal discs, and cartilage that are caused or exacerbated by the environment or nature of work. Previous meta-analyses have characterized work-related musculoskeletal disorders among interventionists, general surgeons, and other surgical subspecialties, but prevalence estimates, prognosis, and ergonomic considerations vary by study and surgical specialty.

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Questions/purposes (1) What is the career prevalence of work-related musculoskeletal disorders in orthopaedic surgeons? (2) What is the treatment prevalence associated with work-related musculoskeletal disorders in orthopaedic surgeons? (3) What is the disability burden of work-related musculoskeletal disorders in orthopaedic surgeons? (4) What is the scope of orthopaedic surgical ergonomic assessments and interventions?

Methods A systematic review of English-language studies from PubMed, MEDLINE, Embase, and Scopus was performed in December 2022 and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Studies that presented prevalence estimates of work-related musculoskeletal disorders or assessed surgical ergonomics in orthopaedic surgery were included. Reviews, case reports, gray literature (conference abstracts and preprints), and studies with mixed-surgeon (nonorthopaedic) populations were excluded. The search yielded 5603 abstracts; 24 survey-based studies with 4876 orthopaedic surgeons (mean age 48 years; 79% of surgeons were men) were included for an analysis of work-related musculoskeletal disorders, and 18 articles were included for a descriptive synthesis of ergonomic assessment. Quality assessment using the Joanna Briggs Institute Tool revealed that studies had a low to moderate risk of bias, largely because of self-reporting survey-based methodology. Because of considerable heterogeneity and risk of bias, prevalence outcomes were not pooled and instead are presented as ranges (mean I^2 = 91.3%).

Results The career prevalence of work-related musculoskeletal disorders in orthopaedic surgeons ranged from 37% to 97%. By anatomic location, the prevalence of work-related musculoskeletal disorders in the head and neck ranged from 4% to 74%; back ranged from 9% to 77%; forearm, wrist, and hand ranged from 12% to 54%; elbow ranged from 3% to 28%; shoulder ranged from 3% to 34%; hip and thigh ranged from 1% to 10%; knee and lower leg ranged from 1% to 31%; and foot and ankle ranged from 4% to 25%. Of orthopaedic surgeons reporting work-related musculoskeletal disorders, 9% to 33% had a leave of absence, practice restriction or modification, or early retirement, and 27% to 83% received some form of treatment. Orthopaedic surgeons experienced biomechanical, cardiovascular, neuromuscular, and metabolic stress during procedures. Interventions to improve orthopaedic surgical ergonomics have been limited, but have included robotic assistance, proper visualization aids, appropriate use of power tools, and safely minimizing lead apron use. In hip and knee arthroplasty, robotic assistance was the most effective in improving posture and reducing caloric expenditure. In spine surgery, proper use of surgical loupes was the most effective in improving posture.

Conclusion Although the reported ranges of our main findings were wide, even on the low end of the reported ranges, work-related musculoskeletal disability among orthopaedic surgeons appears to be a substantial concern. We recommend that orthopaedic residency training programs incorporate surgical ergonomics or work injury lectures, workshops, and film review (alongside existing film review of surgical skills) into their curricula. We suggest hospitals engage in shared decision-making with surgeons through anonymous needs assessment surveys to implement wellness programs specific to surgeons' musculoskeletal needs. We urge institutions to assess surgeon ergonomics during routine quality assessment of novel surgical instruments and workflows.

Level of Evidence Level III, prognostic study.

Introduction

Orthopaedic surgeons perform a higher volume of surgical procedures than other specialists do [63] and exhibit a high degree of resiliency coupled with a strong work ethic [16, 33, 41]. Although these qualities are in many ways desirable for orthopaedic surgeons to possess, such personality traits may predispose orthopaedic surgeons to operating-related overuse injuries during their careers, especially musculoskeletal disorders [24, 67, 68].

The Centers for Disease Control defines musculoskeletal disorders as injuries or disorders of the nerves, muscles, tendons, joints, spinal discs, and cartilage. Moreover, work-related musculoskeletal disorders are conditions in which the work environment or nature of the work results in the manifestation or exacerbation of the condition [8]. Most work-related musculoskeletal disorders occur because of highly repetitive vocational demands, as commonly experienced by manual laborers [19, 21, 55]. The severity of work-related musculoskeletal disorders ranges from minor to disabling and may present with a variety of musculoskeletal pathologies, including back pain, carpal tunnel syndrome, and degenerative spine disease [19].

Studies suggest that orthopaedic surgeons may be at a higher risk of injury than those in other subspecialities [1, 54] because of unique ergonomic challenges that lead to neck flexion, elevated arm positions, extremes of motion, and prolonged standing [42]. The nature of orthopaedic surgery is highly repetitive, characterized by laborious movement and poor ergonomics that may result in work-related musculoskeletal disorders [8, 23, 42, 52, 53, 56]. Prior meta-analyses have characterized the prevalence, prognosis, and burden of musculoskeletal disorders among mixed populations of surgeons, interventionists, and other healthcare professionals [22, 25, 28, 66]. For instance, Epstein et al. [25] reported a high prevalence of neck, shoulder, and back pain in surgical and interventional physicians, but estimates, outcomes, and ergonomic recommendations have varied by study and physician specialty. Thus, a further systematic review of studies of orthopaedic surgeons seems worthwhile to try to reconcile those differences, because orthopaedic surgeons' workplace demands differ from those of other surgical subspecialists.

Our systematic review sought to evaluate the reported burden of work-related musculoskeletal disorders in orthopaedic surgery. We asked: (1) What is the career prevalence of work-related musculoskeletal disorders in orthopaedic surgeons? (2) What is the treatment prevalence associated with work-related musculoskeletal disorders in orthopaedic surgeons? (3) What is the disability burden of work-related musculoskeletal disorders in orthopaedic surgeons? (4) What is the scope of orthopaedic surgical ergonomic assessments and interventions?

Materials and Methods

This systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [57]. We searched PROSPERO to identify any current or unpublished studies on this topic.

Eligibility Criteria

Articles were included if English-language full-text articles were available and the study discussed work-related musculoskeletal disorders in orthopaedic surgeons or performed an ergonomic analysis of orthopaedic surgeons. For this systematic review, an orthopaedic surgeon was defined as an orthopaedic surgery resident, fellow, attending, or equivalent professional. To be included in our quantitative synthesis of work-related musculoskeletal disorders, articles had to report a prevalence estimate of at least one type of work-related musculoskeletal disorder in orthopaedic surgeons. Ergonomic studies were included for descriptive synthesis. Furthermore, articles were excluded if they were systematic reviews, case reports, or gray literature (abstracts and preprint articles), and included nonorthopaedic surgeons (other physician specialties) in study populations.

Search Strategy

A systematic search was conducted in the PubMed, MEDLINE, Embase, and Scopus electronic databases from inception to December 2022 to identify all published studies that analyzed work-related musculoskeletal disorders in orthopaedic surgeons and ergonomic analysis of work-related musculoskeletal disorders in surgeons. Every article was assessed for eligibility by two independent reviewers (HPG and NiV). In case of disagreement, the senior author (JGC) was consulted. The authors developed the search strategy using a combination of keywords and database-specific subject headings (Supplemental Digital Content 1; http://links.lww.com/CORR/B259). Duplicates were removed using Covidence (Veritas Health Innovation).

Study Selection

Our search strategy resulted in 5603 articles from PubMed, MEDLINE, Embase, and Scopus. (Fig. 1). After duplicates were removed, 4426 studies were screened by their title and abstract, and 4376 of them were excluded. Fifty-six articles were assessed for eligibility, and 42 articles met the inclusion criteria. No articles were added after reviewing cited works. Included articles were published between 1995 and 2022. Of the 42 articles, 24 were included in our quantitative synthesis of work-related musculoskeletal disorders [3, 5-13, 15, 17, 23, 24, 27, 42, 49, 52-54, 67, 68, 72, 76] and 18 were included in our descriptive synthesis of orthopaedic ergonomics [14, 26, 29-31, 34, 38, 43-45, 48, 50, 58-60, 64, 65, 73]. No articles assessed both work-related musculoskeletal disorders and surgical ergonomics.

Study Characteristics and Data Extraction

For studies on work-related musculoskeletal disorder, data corresponding to prevalence estimates and surgeon demographics were collected. This included the following: study design, survey tool, orthopaedic subspecialty, geographic location, sample size, response rate, mean or median surgeon age, percentage of surgeons who were men, mean caseload of surgeons (operating hours per week or the number of procedures per week), mean practicing years of the surgeons, reported prevalence estimates of work-related musculoskeletal disorders by anatomic location, and reported risk factors associated with work-related musculoskeletal disorders.

The following broad categories were used to capture work-related musculoskeletal disorders across the entire body: head or neck; shoulder; elbow; forearm, wrist, and hand; back; hip or thigh; knee or lower leg; and foot or ankle. These categories were identified as areas at risk of work-related musculoskeletal disorders [25]. When extracting data for separate anatomic locations in a single study, the maximal injury prevalence for a location in a category was used as the prevalence for the entire category (for example, head and neck work-related musculoskeletal disorders were surveyed separately in some studies, but together as one category in others). This provides a lower-

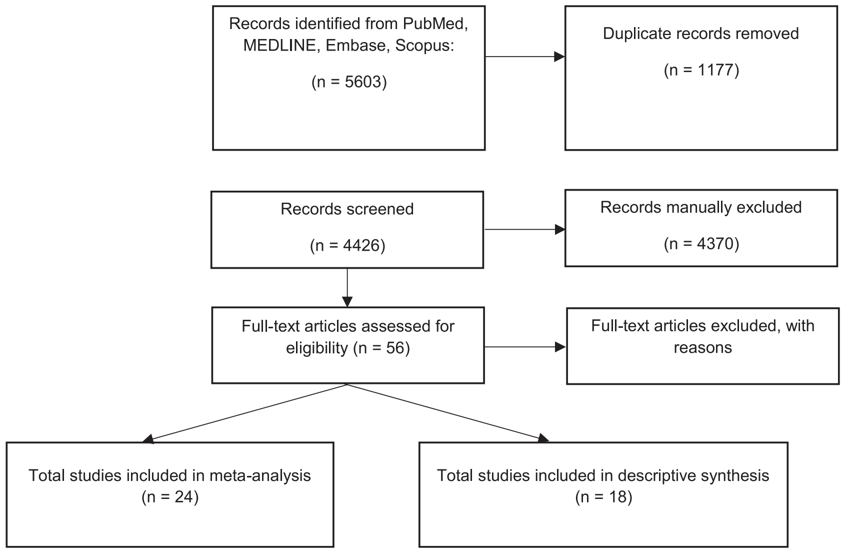

Fig. 1 This Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram shows the included and excluded studies.

bound prevalence estimate of work-related musculoskeletal disorders for categories spanning multiple anatomic locations.

The quantitative synthesis of work-related musculoskeletal disorders included 24 articles that included 4876 orthopaedic surgeons (Table 1). The mean age of the 2083 orthopaedic surgeons in studies that reported a mean age was 48 years, and 79% (3210 of 4062) of orthopaedic surgeons whose gender was recorded were men. Eleven studies used a de novo questionnaire [3, 10, 23, 24, 27, 49, 52-54, 72, 76]. Nine studies used the Physical Discomfort Survey [5, 7–9, 11-13, 42, 67]. Three studies used the Nordic Musculoskeletal Questionnaire [6, 17, 68]. One study used short forms of the Pain Catastrophizing Scale, Patient Health Questionnaire, and Short Health Anxiety Inventory [15]. Eighteen studies captured work-related musculoskeletal disorders across the entire body and reported the overall prevalence of orthopaedic surgeons experiencing one or more work-related musculoskeletal disorders [3, 5-12, 15, 17, 23, 24, 27, 52, 53, 67, 68]. By anatomic location, work-related musculoskeletal disorders were reported in the back in 21 studies [5-13, 15, 17, 23, 24, 42, 49, 53, 54, 67, 68, 72, 76]; the head or neck in 19 studies [3, 5-7, 9, 11-13, 15, 17, 23, 24, 42, 49, 53, 54, 67, 68, 76]; the forearm, wrist, or hand in 19 studies [3, 5-13, 15, 17, 23, 42, 53, 54, 67, 68, 72]; the elbow in 10 studies [6-9, 11, 12, 15, 23, 67, 68], the knee or lower leg in 14 studies [5-9, 11-13, 15, 17, 23, 42, 67, 68]; the shoulder in 13 studies [6-9, 11, 12, 15, 23, 24, 53, 54, 67, 68]; the foot or ankle in 13 studies [5-9, 11, 12, 15, 23, 42, 53, 67, 68], and the hip or thigh in 11 studies [5-7, 9, 11, 12, 15, 23, 42, 67, 68]. The treatment prevalence of work-related musculoskeletal disorders was reported in 11 studies [3, 5, 7, 10, 11, 15, 24, 27, 52, 53, 67]. A measure of work-related musculoskeletal disorders leading to disability was reported in 10 studies [5, 7-9, 11, 12, 15, 23, 24, 67].

For ergonomic studies, intraoperative physiologic data and outcomes of work-related musculoskeletal disorder treatment were collected. This included study design, orthopaedic subspecialty, monitoring method, sample size, and surgeon demographics. Eighteen studies assessed orthopaedic surgical ergonomics through one or a combination of direct biomechanical measurements or indirect physiologic monitoring [14, 26, 29-31, 34, 38, 43-45, 48, 50, 58-60, 64, 65, 73] (Table 2).

Study Quality

The two reviewers (HPG and NiV) independently measured the quality of all included studies using the Joanna Briggs Institute tool [39]. The senior author (JGC) settled disagreements. For all studies, most domains were at low risk of bias (Supplemental Table 1; http://links.lww.com/CORR/B259). Thus, studies were found to be at low risk of overall bias, sufficient for inclusion.

Primary and Secondary Outcomes

Our primary study goal was to estimate the career prevalence of work-related musculoskeletal disorders in orthopaedic surgeons and the associated treatment and disability burden. Our secondary goals were to describe the ergonomic demands

Table 1. Study demographics for meta-analysis

Author	Percent of surveys returned	% men	Mean age in years	Training status (number)	Subspecialties
Acharya et al. [3]	60% (180)	Unknown	Unknown	Unknown	Spine
Alaseem et al. [5]	22% (67)	87% (58)	Unknown	Unknown	Oncology
Al-Mohrej et al. [6]	80% (179)	97% (173)	32	Attending (43) Fellow (26) Resident (110)	All[a]
Alqahtani et al. [7]	17% (578)	85% (490)	Unknown	Unknown	Hand
Alqahtani et al. [8]	15% (86)	85% (73)	Unknown	Unknown	Trauma
Alqahtani et al. [9]	75% (183)	98% (179)	Unknown	Unknown	Arthroplasty
Alsiddiky et al. [10]	83% (39)	97% (38)	45	Unknown	Pediatric
Alzahrani et al. [11]	13% (142)	91% (129)	Unknown	Unknown	Shoulder and elbow
Alzahrani et al. [12]	31% (402)	76% (306)	Unknown	Unknown	Pediatric
Auerbach et al. [13]	62% (561)	Unknown	54	Unknown	Spine
Bernstein et al. [15]	28% (220)	92% (202)	47	Attending (207) Resident (13)	General, trauma, shoulder and elbow, hand and wrist, other
Cacciatori et al. [17]	100% (54)	78% (42)	Unknown	Residents (46) Rest Unknown	NR
Cohen-Rosenblum et al. [23]	NR (63)	0% (0)	Unknown	Unknown	Arthroplasty
Davis et al. [24]	28% (140)	Unknown	50[b]	Unknown	All[a]
Fram et al. [27]	NR (204)	41% (84)	Unknown	Resident (43) Fellow (10) Attending (151)	Arthroplasty, foot and ankle, shoulder and elbow, hand, oncology, pediatrics, spine, sports
Knudsen et al. [42]	82% (32)	75% (24)	29.5	Resident (32)	NR
Lucasti et al. [49]	56% (53)	93% (49)	Unknown	Resident/fellow (15) Attending (38)	NR
McQuivey et al. [53]	NR (76)	72% (55)	30	Resident (76)	N/A
McQuivey et al. [52]	21% (521)	96% (502)	51	Unknown	Arthroplasty
Mirbod et al. [54]	86% (54)	100% (54)	43.3	Unknown	NR
Swank et al. [67]	16% (235)	32% (76)	47	Unknown	All[a]
Tan et al. [68]	70% (56)	91% (51)	33[b]	Attending (20) Resident (34) Unknown (2)	All[a]
Vajapey et al. [72]	25% (66)	Unknown	59	Unknown	NR
Wyatt et al. [76]	NR (685)	91% (625)	Unknown	Unknown	Unknown

[a]All orthopedic surgery specialties (general, upper extremity, lower extremity, pediatrics, spine, sports medicine, trauma, and oncology).
[b]Median age. NR = not reported; N/A = not applicable.

associated with orthopaedic surgery and any evidence-based strategies to improve orthopaedic surgical ergonomics.

Statistical Analysis

Study design and outcome measures varied between ergonomics studies; thus, a descriptive synthesis is presented. Data were analyzed using RStudio (Rstudio, version 2021.09.1+372). To determine whether a meta-analysis was appropriate to estimate the prevalence of work-related musculoskeletal disorders, heterogeneity was calculated using the I^2 statistic. Heterogeneity was substantial (mean $I^2 = 91.3\%$), and studies varied substantially in design and quality. Thus, we present prevalence estimates as ranges and did not pool data for a quantitative

Table 2. Study characteristics for ergonomics descriptive synthesis

Author	Aim	Measured parameters	Assessment timeframe	Setting	Procedure(s) performed	Surgeon age in years	% men	Number, training status
Bergovec et al. [14]	To investigate surgeon energy requirements and cardiovascular response at seven key points during THA; to investigate the effect of age and experience on cardiovascular response	BP, HR, EE	Intraoperative	Surgery	THA	28-65	100	26 attendings
Ferrari et al. [26]	To compare surgeon performance during conventional broaching and using an automated impaction device	sEMG muscle activation (brachioradialis, biceps brachii, trapezius), fatigue	Intraoperative, perioperative	Synthetic composite femur	Automated and conventional broaching	NR	NR	7 attendings
Gupta et al. [29]	To investigate the cardiovascular response of surgeons and trainees during hallux valgus surgery, TKA, and THA; to compare the response between trainers and trainees	BP, HR, MAP, exercise stress test	Intraoperative	Surgery	Hallux valgus correction, TKA, THA	NR	100	3 attendings, 3 residents
Haffar et al. [30]	To investigate the impact of operative laterality and surgeon limb dominance on surgeon physiologic stress and energy expenditure during TJA	HR, HRV, RR, MV, EE	Intraoperative	Surgery	TJA	NR	NR	3 attendings
Haffar et al. [31]	To compare surgeon stress and strain during robotic-assisted TKA and conventional TKA	HR, HRV, RR MV, EE, posture	Intraoperative	Surgery	Unilateral TKA	57-72	NR	NR
Hsiao et al. [34]	To measure the muscle strength and fatigability of the forearm in orthopaedic surgeons performing bone screw fixations	Gripping force, driving torque, push force, sEMG	Intraoperative, perioperative	Porcine femur	Fixation (8 bone screw insertion)	33.8 ± 3.9	100	2 attendings, 6 residents

Table 2. continued

Author	Aim	Measured parameters	Assessment timeframe	Setting	Procedure(s) performed	Surgeon age in years	% men	Number, training status
Jevsevar et al. [38]	To measure physiologic strain in orthopaedic residents and faculty surgeons and identify daily stressors	HRV, RHR, RR, sleep quality	Intraoperative, perioperative	Surgery, clinic	NR	25-41	NR	9 attendings, 12 residents
Kothari and Urakov [43]	To assess the posture of a spine surgeon in various spine surgery cases	Time in nonneutral spine position (slouched)	Intraoperative	Surgery	Spine surgeries	NR	NR	1 attending
Kwon et al. [44]	To measure the intraoperative stress of spine surgeons	HR, HRV, EEG	Intraoperative	Surgery	Elective lumbar spine surgeries	34-65	NR	2 attendings, 3 fellows
Kwon et al. [45]	To analyze intraoperative stress with EEG signals and HRV during spine surgery	HRV, BP, EEG signals	Intraoperative	Surgery	Elective lumbar spine surgeries	34-63	NR	2 attendings, 3 fellows
Lorenz et al. [48]	To measure torques generated by acetabular reamers in THA	Forces and torque along reamer axis	Intraoperative	Fresh frozen cadaver	THA	NR	NR	NR
Mahmood et al. [50]	To evaluate the magnitude of hand-arm vibration exposure in orthopaedic surgeons using a battery-operated saw	Triaxial acceleration	Intraoperative	Fresh frozen cadaver	Tibial bone cut	NR	NR	3 attendings
Park et al. [58]	To assess differences in surgeon whole spine angles according to operating table height and visual aids during discectomy	Whole spine angles	Intraoperative	Simulator	Discectomy	NR	NR	12 attendings
Scheidt et al. [59]	To investigate the impact of front protection X-ray aprons on the posture of orthopaedic and trauma surgeons	Posture	Intraoperative	Surgery	Various	31.07 ± 4.98	65	24 specialist registrars, 2 specialists, 5 senior specialists

Table 2. continued

Author	Aim	Measured parameters	Assessment timeframe	Setting	Procedure(s) performed	Surgeon age in years	% men	Number, training status
Scholl et al. [60]	To compare surgeon cervical spine postures and repetitive motions when performing manual TKA versus robotic-assisted TKA	Cervical spine postures and repetitive motions	Intraoperative	Fresh frozen cadaver	TKA	NR	NR	2 attendings
Sochacki et al. [64]	To determine orthopaedic surgery residents' and attending surgeons' resting HR and HRV and correlated factors	Resting HR, HRV	Intraoperative, perioperative	Surgery, clinic	NR	Resident: 29.8 ± 2.6; attending: 47.2 ± 9.5	Resident: 58; attending: 89	12 residents, 9 attendings
Sochacki et al. [65]	To measure the quantity and quality of sleep in orthopaedic surgeons and correlated factors	Sleep quantity and quality	Intraoperative, perioperative	Surgery, clinic	NR	37.2 ± 10.9	71%	12 residents, 9 attendings
Whitney et al. [73]	To measure EE during simulated orthopaedic spine surgery	VO2, EE, fat and carbohydrate utilization	Intraoperative	Fresh frozen cadaver	One-level lumbar laminectomy and fusion	32 ± 2	NR	1 attending, 7 residents

Data presented as range or mean ± SD. BP = blood pressure; HR = heart rate; EE = energy expenditure; sEMG = surface electromyography; NR = not reported; MAP = mean arterial pressure, HRV = heart rate variability; RR = respiratory rate; RHR = resting heart rate; MV = minute ventilation; TJA = total joint arthroplasty; EEG = electroencephalography.

meta-analysis. Because pooling was not done, we did not use funnel plots to look for the possibility of positive outcome bias.

Results

Career Prevalence of Work-related Musculoskeletal Disorders

The overall career prevalence estimate of work-related musculoskeletal disorders ranged from 37% to 97% (Table 3). By anatomic location, the prevalence of work-related musculoskeletal disorders in the head or neck ranged from 4% to 74%; back ranged from 9% to 77%; forearm, wrist, or hand ranged from 12% to 54%; elbow ranged from 3% to 28%; shoulder ranged from 3% to 34%; hip or thigh ranged from 1% to 10%; knee or lower leg ranged from 1% to 31%; and foot or ankle ranged from 4% to 25%. Ranges of prevalence estimates may have been wide because of variability in surgeon subspecialty (thus, procedures performed and mechanisms of injury could vary).

Percentage of Surgeons Seeking Treatment

Overall, 27% to 83% of surgeons with work-related musculoskeletal disorders received treatment, including medications, surgery, time off or a leave of absence, or physical therapy because of work-related musculoskeletal disorders (Table 3). The range may have been wide because of variability in institutional resources or cultural differences (institutional or geographic bias) between included studies.

Burden of Disability

The estimate of work-related musculoskeletal disorder-afflicted orthopaedic surgeons who experienced disability was 9% to 33% of surgeons with work-related musculoskeletal disorders (Table 3). Disability included a leave of

Table 3. Studies reporting an overall work-related musculoskeletal disorder, treatment, or disability prevalence

Author	Survey tool	Number surveyed	Overall work-related MSD prevalence	Treatment prevalence of work-related MSDs	Work-related MSDs leading to disability
Cohen-Rosenblum et al. [23]	De Novo	63	68.3% (43)	NR	9.3% (4)
Davis et al. [24]	De Novo	140	44% (61)	39% (34)	23% (14)
Fram et al. [27]	De Novo	204	69.1% (141)	47.5% (67)	NR
McQuivey et al. [53]	De Novo	76	97% (74)	62% (46)	NR
McQuivey et al. [52]	De Novo	521	97% (503)	62% (312)	NR
Alaseem et al. [5]	PDS	67	76.1% (51)	27.5% (14)	33.3% (17)
Alqahtani et al. [9]	PDS	183	66.1% (121)	NR	27.3% (33)
Alqahtani et al. [8]	PDS	86	66.3% (57)	NR	26.3% (15)
Alqahtani et al. [7]	PDS	578	60.4% (349)	73.1% (255)	29.2% (102)
Alzahrani et al. [12]	PDS	402	66.9% (269)	NR	30.9% (83)
Alzahrani et al. [11]	PDS	142	89.4% (127)	82.7% (105)	26.0% (33)
Swank et al. [67]	PDS	235	86% (202)	27% (55)	14% (28)
Al-Mohrej et al. [6]	NMQ	179	67% (120)	NR	NR
Caciatori et al. [17]	NMQ	54	37% (20)	NR	NR
Tan et al. [68]	NMQ	56	87.5% (49)	NR	NR
Bernstein et al. [15]	PCS, PHQ, SHAI	220	83% (183)	53% (96)	13% (23)

MSD = musculoskeletal disorder; PDS = Physical Discomfort Survey; NMQ = Nordic Musculoskeletal Questionnaire; PCS = Pain Catastrophizing Scale; PHQ = Patient Health Questionnaire; SHAI = Short Health Anxiety Inventory; NR = not reported.

absence, practice restriction or modification, or early retirement. Four studies surveyed surgeons about whether they believed their work-related musculoskeletal disorders would negatively impact their ability to operate in the future. Three studies found that 33% to 39% of orthopaedic surgeons with a work-related musculoskeletal disorder believed their disorder would negatively impact future procedures [10, 53, 72]. One study reported that 59% of orthopaedic surgeons with a work-related musculoskeletal disorder believed it influenced their surgical ability [52].

Ergonomic Assessment and Interventions

Ergonomic assessment revealed several sources of biomechanical stress in the upper extremities [26, 34, 48, 50] and spine [31, 43, 58-60]. Orthopaedic surgeons commonly experienced upper extremity "fatigue" while performing surgery; for example, a reduction in maximal grip force, driving torque, and push force after performing fixation of femoral fractures [34]. Power tools can improve surgical ergonomics but should be used appropriately and cautiously. One study reported that using a battery-operated saw for more than 23 minutes transmitted levels of hand-arm vibration exceeding the exposure threshold set by the Health and Safety Executive [50]. Another study reported hazardous peak torques at the wrist along the reamer axis during acetabulum preparation, potentially contributing to wrist pathology [48]. However in THA, automated impaction during femoral broaching was associated with lower levels of muscle activation by surface EMG and lower reported fatigue than with manual broaching [26].

Two studies reported a potential benefit of robotic-assisted TKA with regard to cervical, thoracic, and lumbar strain compared with manual TKA [31, 60]. Common spine surgeries are associated with poor posture, with one study reporting that the proportion of operative time spent in a non-neutral (slouched) spine position while performing cervical and lumbar spine surgery was 39.9%, 58.9%, and 38.5% [43]. However, proper use of visualization aids in spine surgery may mitigate postural ergonomic hazards. One study reported that lumbar lordosis, cervical lordosis, occipital angle, and thoracic kyphosis were closest to the natural standing position during simulated discectomy while using surgical loupes versus the naked eye or out-of-loupe visualization [58]. Lead aprons are another postural biomechanical hazard, and one study reported that lead apron use was associated with increased forefoot load and thoracic kyphosis with a lateral bending [59]. Additionally, surgeons reported less back pain on operating room days without lead apron use versus operating room days with lead apron use [59].

Ergonomic assessment revealed that orthopaedic surgeons are subject to various sources of physiologic stress [14, 26, 29-31, 34, 38, 44, 45, 64, 65, 73]. Orthopaedic surgery is associated with substantial caloric expenditure and metabolic demand [14, 30, 31, 73]. However, the metabolic demands of THA can be reduced by using robotic assistance [30]. Orthopaedic surgeons also experience cardiovascular and mental stress during procedures [14, 29-31, 38, 44, 45, 64]. Two studies reported high intraoperative stress using EEG and cardiovascular parameters, and associated less training experience with increased physiologic stress [44, 45]. Orthopaedic surgeons had greater mean blood pressure and heart rate on operative days than at baseline [29]. Certain steps of the procedure may cause greater physiologic stress, with one study reporting that stress peaked during femoral preparation, trialing, and implantation in THA [14]. Lifestyle modifications such as improved sleep quality may mitigate the physiologic strains associated with orthopaedic surgery [38, 65].

Discussion

Characterizing the work-related musculoskeletal disorders, associated outcomes, and ergonomic demands of orthopaedic surgeons is critical for improving surgeon and patient outcomes. Orthopaedic surgeons experience a high career prevalence of work-related musculoskeletal disorders, many of which go untreated and result in substantial disability. Although the reported ranges of our main findings were wide, even on the low end of the reported ranges, work-related musculoskeletal disability among orthopaedic surgeons appears to be a substantial concern. The most conservative estimates suggest that nearly four of 10 surgeons report having experienced a work-related musculoskeletal injury, with more than one-fourth of them undergoing treatment for the injury. The most common locations of work-related musculoskeletal disorders were the head or neck; back; and forearm, wrist, or hand. Moreover, the findings of this systematic review suggest that orthopaedic surgical procedures are associated with substantial biomechanical, cardiovascular, neuromuscular, and metabolic demands. Strategies to improve surgical ergonomics included the use of robotic assistance in TKA and THA, surgical loupes in spine surgery, and automated impaction devices in THA. Although a limited number of studies proposed interventions to improve orthopaedic surgical ergonomics, several targeted interventions were successful in other fields [18, 20, 37]. To improve orthopaedic surgical ergonomics and mitigate work-related musculoskeletal disorders, we recommend ergonomics and work-injury lectures be offered by hospitals and residency training curricula, and film-based review of surgical techniques to assesses ergonomics in addition to surgical skill. Future studies might evaluate surgeon ergonomics during quality assessments of novel surgical instruments and techniques.

Limitations

The bias assessment of the evidence demonstrated several limitations. Of the 24 cross-sectional studies describing the prevalence of work-related musculoskeletal disorders, all used convenience sampling and only eight achieved a response rate of at least 60%, suggesting selection bias. A related limitation is social desirability bias. Although most studies administered surveys online via email and social media, a few studies conducted surveys in person and to patients at the same institution. Selection and social desirability bias are likely the leading contributors to study heterogeneity. For example, geographic (cultural) differences may influence a surgeon's perception of a musculoskeletal disorder (for example, musculoskeletal pain), and institutional resources may influence outcomes after a work-related musculoskeletal disorder. However, our systematic review did not reveal any institutional resources to mitigate work-related musculoskeletal disorders for orthopaedic surgeons, highlighting a gap to explore in a future study. Another limitation is misclassification or self-reporting bias, because all primary data were acquired through self-report instruments. Because all study participants were specialists in musculoskeletal health, it is unlikely that self-reporting or misclassification bias contributed substantially to outcome heterogeneity. Nevertheless, one must exercise caution when interpreting the reported prevalence estimate ranges, because individual studies could overestimate the frequency and severity of work-related musculoskeletal disorders because of positive outcome (publication) bias or for secondary gain (for example, to promote a specific intervention or surgical device). Because of these sources of bias and heterogeneity between studies, we were unable to perform a meta-analysis.

Discussion of Key Findings

This systematic review found that orthopaedic surgeons experience a high career prevalence of work-related musculoskeletal disorders, and that there are limited interventions to improve orthopaedic surgical ergonomics and prevent work-related musculoskeletal disorders. Epstein et al. [25] reported that most surgical training programs provide neither formal (98%) nor informal (75%) surgical ergonomics training. This indicates that surgeons, including orthopaedic surgeons, likely do not have access to evidence-based surgical ergonomics training, which may increase their risk of experiencing work-related musculoskeletal disorders in their careers. Thus, hospitals and orthopaedic surgery residency programs should offer orthopaedic-specific ergonomics or work injury lectures and workshops (for Continuing Medical Education credit), which have been successfully implemented in general surgery training programs [20, 37]. Because randomized controlled trials with longitudinal ergonomic and work injury monitoring are impractical, the success of ergonomic lectures and workshops ought to be defined by an increase in knowledge and awareness of one's own habits while operating, and the perceived benefit by the surgeon. The emerging adoption and projected growth of film review by hospitals to facilitate the surgical training of residents and practicing surgeons can further increase ergonomic awareness [18]. We propose that film review be used to evaluate not only surgical skills, but also surgical ergonomics, either informally or through the use of validated observational tools [1, 2, 32, 51]. Through ergonomic education, surgeons can continue to improve their surgical skills and patient outcomes while improving ergonomics throughout their careers [71].

Because orthopaedic surgeons must repeatedly work in strained postures with repetitive motions, the mechanisms of injury parallel overuse injuries in athletes [4, 47, 70, 74, 75]. Elite-level athletes report a high prevalence of overuse injuries, which is consistent with our findings among orthopaedic surgeons with regard to work-related musculoskeletal disorder estimates [47, 70, 74, 75]. High-performance athletes routinely assess their biomechanical and physiologic loads through objective measurement with wearable sensors and motion capture analysis [61, 62]. It is impractical to study the ergonomics of all existing surgical tools and techniques with the same rigor as with athletes. However, we propose that institutions include a surgeon-centric ergonomic assessment during the quality assessment of novel surgical instruments and workflows before their implementation. Such assessment could be achieved through ergonomic film review, wearable devices to measure physiologic strain, or survey of surgeons' perceptions [14, 18, 31, 32, 60].

Although not all work-related musculoskeletal disorders lead to disability in orthopaedic surgeons, many orthopaedic surgeons with a work-related musculoskeletal disorder do not seek treatment, which included time off, a leave of absence, physical therapy, medications, or surgery. Minor aches and pains certainly do not warrant aggressive treatment, but this behavior may parallel that of elite or professional athletes, who may be intrinsically and extrinsically motivated to work through injury or pain [75]. Thus, further study is needed to understand orthopaedic surgeons' attitudes toward seeking treatment for work-related musculoskeletal disorders, with specific emphasis on the psychologic and sociologic perspectives of orthopaedic surgeons regarding workplace culture. To date, such research has predominantly focused on physician burnout as opposed to workplace injury [5, 35, 36, 69]. We propose to incorporate domains of work-related injury and treatment into ongoing burnout and wellness initiatives, such as anonymous needs assessment surveys in which physicians rank wellness topics and interventions in order of importance [40, 46]. By involving the surgeons in the creation of targeted work-injury resources and wellness initiatives, institutions can avoid overtreating or undertreating work-related musculoskeletal disorders.

Conclusion

This systematic review found that the prevalence of work-related musculoskeletal disorders among orthopaedic surgeons is high and may lead to disability. Although the reported ranges for our main findings were wide, even at the lower end of these reported ranges, work-related musculoskeletal disability among orthopaedic surgeons appears to be extremely common. The lowest estimates indicate that nearly 40% of orthopaedic surgeons reported experiencing a work-related musculoskeletal disorder, and more than 25% of them sought treatment for it. The most common locations of work-related musculoskeletal disorders were the head or neck; back; and forearm, wrist, or hand. Despite the potential impact of these work-related musculoskeletal disorders on career longevity and physical discomfort, many surgeons may not be receiving adequate treatment. We propose that institutions use anonymous needs assessment surveys to involve surgeons in implementing wellness and treatment resources that are appropriate to the severity of their symptoms. Although initial survey-based efforts to assess the current state of ergonomics in orthopaedic surgery help identify and quantify the physical burden experienced in the operating room, few studies have aimed to assess the ergonomics of specific interventions with objective biomechanical and physiologic metrics. We recommend that institutions assess surgical ergonomics when conducting quality assessments of novel surgical instruments and workflows before their implementation. We also recommend that institutions offer ergonomics education through lectures, workshops, or ergonomic film review to residents and practicing physicians. Beyond ergonomics, orthopaedic surgeon health should be studied with the same rigor as that of the patients they treat, with rigorous research, interventions, and training to promote health and career longevity.

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