Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Dose-Response Relationships Between Dynamic Work Exposures and Musculoskeletal Disorders Among Operating Room Staff: A Prospective Longitudinal Study

Yang Jia-Wen[1]
Operating Room, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine
Jian Guo[1]
Operating Room, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine
Chen Yuan[1]
cherry_chen1215@163.com
Operating Room, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine

Article

Keywords: operating room staff, work-related musculoskeletal disorders, dose-response model, occupational health, prospective longitudinal study, body composition, nursing

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10885101/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Dose-Response Relationships Between Dynamic Work Exposures and Musculoskeletal Disorders Among Operating Room Staff: A Prospective Longitudinal Study

Yang Jia-Wen[1]*, Jian Guo[1]*, Chen Yuan[1]

[1] Operating Room, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200025, China

*These authors contributed equally.

Corresponding author: Chen Yuan, Operating Room, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, No. 197 Ruijin Er Road, Shanghai 200025, China. Email: [cherry_chen1215@163.com]

Word count: Abstract [298 words]; Main text [~4,800 words]

Figures/Tables: 5 tables, 1 figure

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of [Shanghai Jiao Tong University School of Medicine Affiliated Ruijin Hospital] (approval number: [2026-646]). Written informed consent was obtained from all participants. All methods were performed in accordance with the Declaration of Helsinki and relevant guidelines.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to participant privacy considerations but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

YJW: Conceptualization, Formal analysis, Methodology, Writing - original draft. GJ: Data curation, Investigation. CY: Conceptualization, Methodology, Project administration, Supervision, Writing - review & editing. All authors read and approved the final manuscript.

Acknowledgements

The authors thank all the operating room staff at Ruijin Hospital who participated in this study for their time and commitment. We also acknowledge the OR nursing management team for their administrative support during the data collection period.

Abstract

Background

Operating room (OR) staff are at exceptionally high risk for work-related musculoskeletal disorders (WMSDs), yet longitudinal evidence quantifying the dose-response relationship between dynamic daily exposures and musculoskeletal outcomes remains scarce. This study aimed to quantify these dose-response associations and identify exposure thresholds predictive of moderate-to-severe pain.

Methods

A prospective longitudinal design was used to follow 40 OR healthcare workers (20 surgeons, 20 nurses) from a tertiary hospital in Shanghai, China, over four consecutive working weeks (20 workdays). Daily overtime hours, duration of awkward postures, and frequency of heavy lifting (>5 kg) were recorded alongside daily pain scores (Visual Analogue Scale, 0-10) and fatigue levels (Fatigue Scale-14). Body composition was assessed at baseline and endpoint via bioelectrical impedance analysis. Hierarchical multiple linear regression was used to construct dose-response models, with subgroup analyses by profession and work seniority.

Results

The lifetime WMSDs prevalence was 100%, with the lower back (VAS 6.2±1.8), neck (5.8±1.7), and shoulders (5.5±1.6) most affected. Nurses reported significantly higher pain (5.5±1.4 vs. 4.7±1.2, P=0.049) and longer sick leave (6.8±3.2 vs. 4.5±2.7 days, P=0.019) than surgeons. After controlling for baseline characteristics, each additional hour of awkward posture increased pain by 0.45 points (β=0.450, P<0.001), each overtime hour by 0.32 points (β=0.320,

P<0.001), and each heavy-lifting event by 0.28 points (β=0.275, P<0.001). The full model explained 68.7% of pain variance. Exposure thresholds of ≥3.6 overtime hours, ≥5.1 hours of awkward posture, and ≥12 daily lifts corresponded to VAS scores exceeding 7. Nurses and staff with >20 years of seniority showed stronger dose-response effects.

Conclusions

A clear dose-response gradient exists between dynamic work exposures and musculoskeletal pain among OR staff, with identifiable thresholds for moderate-to-severe pain. Profession-specific and seniority-stratified prevention strategies are urgently needed.

Keywords:

operating room staff; work-related musculoskeletal disorders; dose-response model; occupational health; prospective longitudinal study; body composition; nursing

Background

Work-related musculoskeletal disorders (WMSDs) refer to chronic injuries of muscles, bones, joints, tendons, ligaments, and bursae caused or aggravated by occupational activities [1]. Globally, approximately 1.7 billion people live with some form of musculoskeletal condition, and WMSDs account for an estimated economic loss exceeding $125 billion annually, representing 0.5%-1.0% of global GDP [2]. Among healthcare workers, WMSDs prevalence is consistently higher than in most other industries, constituting a leading cause of work disability, reduced productivity, and premature career attrition [3,4].

The operating room (OR) represents a uniquely high-risk environment. OR staff are routinely required to maintain non-neutral postures -- such as prolonged standing, trunk flexion, cervical anteflexion, and arm elevation -- while simultaneously performing repetitive fine-motor tasks including instrument passing, suturing, and equipment manipulation [5]. These demands are compounded by patient transfer, positioning, and heavy equipment handling. International studies report lifetime WMSDs prevalence rates of 80%-90% among OR personnel, with the lower back (60%-70%), neck (50%-60%), and shoulders (40%-50%) as the most affected anatomical sites [6,7]. In China, cross-sectional surveys have reported prevalence rates of approximately 85.2% among OR nurses and 78.9% among surgeons, with trends toward younger age of onset and multi-site involvement [8,9].

Despite a substantial body of evidence on risk factors, several critical gaps persist in the literature. First, the overwhelming majority of studies have employed cross-sectional designs, which can identify associations but cannot establish the causal sequence between temporal fluctuations in daily exposure and subsequent pain or fatigue outcomes [10]. Second, although overtime hours, awkward posture duration, and heavy lifting frequency are conceptually

recognized as cumulative exposures, their quantitative dose-response relationships with musculoskeletal pain have rarely been formally modeled in OR populations [11]. Without such quantification, it is difficult to pinpoint actionable exposure thresholds at which the risk of moderate-to-severe pain escalates meaningfully. Third, most studies have treated surgeons and nurses as a homogeneous group, overlooking fundamental differences in task profiles, posture patterns, and workload distributions between these two professions [12,13]. Fourth, although body composition indicators -- particularly skeletal muscle mass, body fat percentage, and visceral fat level -- are plausible modulators of musculoskeletal load and inflammatory milieu, their dynamic changes during sustained work exposure and their interactive role with ergonomic stressors remain underexplored in OR settings [14].

The dose-response model, widely applied in occupational and environmental epidemiology, offers a rigorous framework for linking graded exposure levels to graded health outcomes, thereby enabling identification of effect thresholds and quantification of exposure-response slopes [15]. In the context of OR WMSDs, this approach can transform qualitative risk factor lists into operationally actionable metrics for occupational health management.

Accordingly, the present study adopted a prospective longitudinal design with four objectives: (1) to describe the prevalence and distribution patterns of WMSDs among OR physicians and nurses; (2) to characterize their dynamic daily work exposures, fatigue trajectories, and body composition changes over four consecutive working weeks; (3) to quantify the dose-response relationships between daily overtime hours, awkward posture duration, and heavy lifting frequency with musculoskeletal pain, controlling for baseline demographics; and (4) to compare dose-response patterns across profession and work-seniority subgroups, thereby informing stratified prevention strategies.

Methods

Study Design and Setting

This prospective longitudinal study was conducted between March 16 and April 12, 2026, in the digestive surgery operating suite of Ruijin Hospital, Shanghai Jiao Tong University School of Medicine -- a 2,800-bed tertiary teaching hospital with 35 operating rooms and an annual surgical volume of approximately 80,000 procedures. The digestive surgery suite was selected because its staff are assigned on a fixed-suite basis without frequent cross-suite rotation, which facilitated four consecutive weeks of uninterrupted daily tracking.

Participants

Eligibility criteria included: (1) full-time employment as a surgeon or nurse in the OR for ≥1 year; (2) clear consciousness, adequate communication and literacy skills to complete daily assessments; (3) voluntary participation with written informed consent; and (4) fixed assignment to the digestive surgery suite with no planned off-site rotation, training, or extended leave during the tracking period. Exclusion criteria were: (1) acute musculoskeletal injury within one month prior to enrollment, or diagnosed severe chronic musculoskeletal disease, rheumatologic/autoimmune conditions, or prior spinal surgery that could confound pain assessment; (2) pregnancy or lactation; (3) planned absence of >1 week during the tracking period; and (4) severe cardiovascular, hepatic, renal, or neoplastic diseases that could affect body composition or fatigue evaluation.

A priori sample size was calculated using G*Power 3.1 for hierarchical multiple linear regression with a medium effect size (f^2=0.15), α=0.05, and 1-β=0.80, with 3-4 predictors, yielding a minimum requirement of 15-18 participants per subgroup. Accounting for a 10%

attrition rate, 20 surgeons and 20 nurses were enrolled (total N=40). Of 45 informed consent forms distributed, 40 were returned with valid consent (response rate 88.9%).

Data Collection Procedures

The study comprised three phases: baseline survey (Day 1), daily tracking (20 workdays), and endpoint survey (Day 20).

Baseline survey (March 16, 2026). After obtaining informed consent, participants completed a demographic and occupational questionnaire and the standardized Nurse Occupational Musculoskeletal Disorders Questionnaire (a validated 43-item instrument developed for Chinese healthcare populations; test-retest reliability 0.82-0.91, content validity index 0.86) [16]. They then underwent body composition measurement using the InBody H40 analyzer (Biospace Co., Seoul, Korea), which employs multi-frequency bioelectrical impedance analysis (BIA) to quantify body weight, skeletal muscle mass, body fat mass, body fat percentage, visceral fat level, waist-hip ratio, basal metabolic rate, and lower-limb muscle grade. Baseline fatigue was assessed using the Fatigue Scale-14 (FS-14; Cronbach α=0.78-0.85 in Chinese occupational populations) [17].

Daily tracking (March 17-April 12, 2026; 20 workdays). At the end of each workday (approximately 17:00-22:00), two trained research assistants visited the OR lounge and administered: (a) a daily exposure log recording overtime hours, primary work postures and their cumulative duration, number of heavy-lifting events (>5 kg) and maximum weight lifted; (b) the Visual Analogue Scale (VAS, 0-10) for pain at nine anatomical sites (neck, shoulders, upper back, elbows, lower back, wrists/hands, hips, knees, ankles/feet), averaged to produce a total daily VAS score; and (c) the FS-14 for daily fatigue. For participants who completed late surgeries or were absent, make-up assessments were conducted within 24 hours.

Endpoint survey (April 12, 2026). The standardized MSDs questionnaire was re-administered, and body composition was re-assessed using the same InBody H40 protocol.

Variables and Instruments

The primary outcome was the daily total VAS pain score (mean of nine body sites). Secondary outcomes included the daily FS-14 fatigue score (total, physical subscale, mental subscale), 4-week body composition changes, and cumulative sick leave days attributable to WMSDs. Primary exposure variables were daily overtime hours (continuous), daily cumulative duration of awkward postures (continuous, hours), and daily number of heavy-lifting events (>5 kg; continuous). Awkward postures were defined as any non-neutral sustained position, including trunk flexion, cervical anteflexion, arm elevation, wrist deviation, or combined flexion-rotation, as self-reported daily. Baseline covariates extracted from the general questionnaire included age, sex, profession (surgeon/nurse), professional title, work seniority, weekly working hours, shift work status, self-rated health, and physical exercise frequency.

Statistical Analysis

All analyses were performed using SPSS 26.0 (IBM Corp., Armonk, NY) with two-tailed $\alpha=0.05$. Descriptive statistics were reported as mean±standard deviation (SD) for continuous variables and frequency (percentage) for categorical variables. Independent-samples t-tests compared surgeons and nurses on continuous outcomes; chi-square tests compared categorical variables. Paired-sample t-tests compared baseline and endpoint body composition indices. Pearson correlation coefficients assessed bivariate associations between daily exposures and outcomes.

The core analysis employed hierarchical multiple linear regression to construct dose-response models. In Step 1, baseline demographic covariates (age, sex, work seniority, professional title) were entered as control variables. In Step 2, the three continuous exposure variables were added simultaneously to estimate their independent contributions. The standardized regression coefficient (β) for each exposure represented the increment in VAS pain score per one-unit increase in the exposure, adjusted for covariates and all other exposures. To identify clinically meaningful thresholds, exposure variables were categorized into quartiles, and one-way ANOVA with polynomial contrast tested for linear trends across quartile groups. Dose-response models were then reconstructed separately for surgeon and nurse subgroups and for four work-seniority strata (1-5, 6-10, 11-20, and >20 years), with between-group differences in regression coefficients compared using Chow tests.

Model assumptions -- linearity, normality of residuals, homoscedasticity, and absence of severe multicollinearity (variance inflation factor <5) -- were verified for all regression models.

Ethical Considerations

This study was approved by the Institutional Review Board of Ruijin Hospital, Shanghai Jiao Tong University School of Medicine [approval number to be inserted]. Written informed consent was obtained from all participants. All data were anonymized and stored securely, accessible only to the research team.

Results

Participant Characteristics

All 40 enrolled participants completed the 4-week tracking without attrition. The sample comprised 20 surgeons and 20 nurses, predominantly female (80.0%), with a mean age

concentrated in the 26-35 year range (52.5%). All held bachelor degrees or above (bachelor 80.0%, master or above 20.0%). Work seniority was distributed as: 1-5 years (35.0%), 6-10 years (17.5%), 11-20 years (22.5%), and >20 years (25.0%). Mean weekly working hours were 57.4 h, 82.5% were shift workers, only 12.5% engaged in regular exercise ≥3 times/week, and 97.5% reported feeling fatigued after work. No statistically significant differences were found between surgeons and nurses on any baseline demographic or occupational characteristic (all $P>0.05$), confirming group comparability. (Table 1)

Prevalence and Distribution of WMSDs

The lifetime WMSDs prevalence was 100% across all nine anatomical sites except elbows (95.0%). Over the past year and past week, all nine sites showed 100% pain prevalence, and 100% of participants reported having taken sick leave attributable to musculoskeletal pain. The overall mean past-week VAS was 5.1±1.3, with the lower back scoring highest (6.2±1.8), followed by the neck (5.8±1.7) and shoulders (5.5±1.6). The lower back was the leading cause of sick leave (95.0% of participants), followed by the neck (87.5%) and shoulders (80.0%). (Table 2)

Nurses reported significantly higher mean VAS scores than surgeons (5.5±1.4 vs. 4.7±1.2, $t=2.045$, $P=0.049$) and longer cumulative WMSDs-related sick leave (6.8±3.2 vs. 4.5±2.7 days, $t=2.476$, $P=0.019$).

Daily Work Exposure and Fatigue Trajectories

Over the 20-workday tracking period, the mean daily overtime was 2.5±1.2 h, mean daily awkward posture duration was 4.2±1.5 h, and mean daily heavy lifting (>5 kg) frequency was 8.5±3.2 events (Table 3). Nurses recorded significantly longer daily awkward posture duration

(4.9±1.6 vs. 3.5±1.2 h, P=0.004) and more frequent heavy-lifting events (10.2±3.4 vs. 6.8±2.5, P=0.001) than surgeons. Overtime hours did not differ significantly between groups (2.8±1.3 vs. 2.2±1.0 h, P=0.103).

Rest breaks were severely inadequate: 30.0% of participants had no rest breaks during any work shift; the median cumulative break time per shift was only 10 minutes; and 37.5% averaged ≤5 minutes of break time per shift. All participants (100%) considered break time insufficient and reported being unable to autonomously decide when to rest.

Mean daily FS-14 fatigue score was 8.7±1.3, displaying a clear within-week accumulation pattern: lowest on Monday (7.8±1.2), rising progressively to a peak on Friday (9.5±1.1). Daily VAS pain showed a parallel trajectory (Monday 4.2±1.1 to Friday 5.8±1.4), confirming a work-accumulation effect. Nurses scored significantly higher on the FS-14 total (9.1±0.8 vs. 7.9±1.3, P=0.001) and physical fatigue subscale (6.2±0.7 vs. 5.2±1.0, P<0.001) than surgeons.

Body Composition at Baseline and 4-Week Changes

At baseline, 62.5% of participants had elevated body fat percentage, 55.0% had elevated visceral fat level, and 47.5% had below-normal skeletal muscle mass. Notably, 72.5% were classified as C-type physique (inadequate muscle mass and/or excessive body fat). After four weeks of continuous tracking, significant deteriorations were observed: mean body fat increased by 0.6 kg (P=0.014), body fat percentage rose by 0.8% (P=0.008), visceral fat level increased by 0.3 grade (P=0.049), and skeletal muscle mass decreased by 0.3 kg (P=0.036). Nurses showed significantly greater deterioration than surgeons in both body fat percentage increase (+1.1±0.5% vs. +0.5±0.4%, P<0.001) and skeletal muscle loss (-0.4±0.2 vs. -0.2±0.1 kg, P=0.001). (Table 4)

Dose-Response Relationships Between Work Exposures and Musculoskeletal Pain

Pearson correlations confirmed strong positive associations of all three exposures with daily VAS pain (awkward posture duration: r=0.756; overtime: r=0.682; heavy lifting: r=0.625; all P<0.001) and with daily FS-14 fatigue (overtime: r=0.723; posture: r=0.698; lifting: r=0.587; all P<0.001).

Hierarchical regression results are presented in Table 5. Model 1 (baseline covariates only) explained merely 12.5% of VAS pain variance (adjusted R^2=0.087, F=3.267, P=0.023), with only work seniority approaching significance (P=0.059). After entering the three exposure variables, Model 2 explained 68.7% of variance (adjusted R^2=0.652, ΔR^2=56.2%, F=19.654, P<0.001). In the fully adjusted model, each additional hour of awkward posture increased VAS pain by 0.45 points (β=0.450, t=5.318, P<0.001), each additional overtime hour by 0.32 points (β=0.320, t=4.115, P<0.001), and each additional heavy-lifting event by 0.28 points (β=0.275, t=4.029, P<0.001).

Quartile-based analyses demonstrated clear graded dose-response patterns (Figure 1). Across increasing quartiles of overtime hours (Q1: ≤1.5 h to Q4: ≥3.6 h), VAS scores rose from 3.8±0.9 to 7.2±1.3 (F=28.765, P for trend <0.001). For awkward posture duration (Q1: ≤3.0 h to Q4: ≥5.1 h), VAS scores rose from 3.5±0.8 to 7.5±1.4 (F=35.432, P<0.001). For heavy-lifting frequency (Q1: ≤5 to Q4: ≥12 events/day), VAS scores rose from 4.0±1.0 to 6.8±1.3 (F=22.567, P<0.001). The fourth quartile of each exposure corresponded to VAS scores exceeding 7, a clinically recognized threshold for moderate-to-severe pain.

Subgroup Analyses: Profession and Work Seniority

Profession-stratified models revealed that awkward posture duration exerted a significantly stronger effect in nurses (β=0.51, P<0.001) than in surgeons (β=0.37, P<0.001;

between-group difference P=0.031). Overtime (nurse β=0.35 vs. surgeon β=0.28) and heavy lifting (β=0.33 vs. β=0.22) effects were numerically higher in nurses but did not reach statistical significance for between-group differences.

Work-seniority-stratified models demonstrated a monotonic gradient: the effect of overtime on pain increased from β=0.25 (1-5 years) to β=0.42 (>20 years; P for trend=0.012), and the effect of awkward posture increased from β=0.38 (1-5 years) to β=0.56 (>20 years; P for trend=0.018). Heavy-lifting effects showed a similar but non-significant trend (β=0.21 to β=0.34; P=0.135). These results indicate that both profession and cumulative career exposure moderate the dose-response relationship between work exposures and musculoskeletal pain.

Discussion

This prospective longitudinal study provides compelling evidence for a graded, quantifiable dose-response relationship between three key dynamic work exposures -- overtime hours, awkward posture duration, and heavy-lifting frequency -- and musculoskeletal pain among OR healthcare workers. Three findings are particularly noteworthy: the identification of specific, operationally actionable exposure thresholds above which moderate-to-severe pain becomes prevalent; the differential susceptibility of nurses versus surgeons and of senior versus junior staff; and the documented, rapid deterioration of body composition over a mere four weeks of routine clinical work.

WMSDs Burden: Confirmatory Evidence and New Insights

The 100% lifetime and past-week WMSDs prevalence observed in this sample exceeds most previous estimates in the literature, which have generally ranged from 80% to 90% [6,7]. This discrepancy likely reflects the sampling context -- a high-volume tertiary hospital in an

urban Chinese setting with a mean weekly workload of 57.4 hours, substantially exceeding the standard 40-hour workweek -- and the improved detection sensitivity afforded by daily prospective assessment, which minimizes recall bias that plagues cross-sectional surveys [18]. The anatomical hierarchy of pain -- lower back > neck > shoulders -- is consistent with the biomechanical demands of OR work, where sustained trunk flexion, cervical anteflexion during instrument manipulation, and arm elevation for equipment handling converge on these three sites [19]. Notably, the finding that nurses experienced significantly higher pain intensity and longer sick leave than surgeons, despite comparable baseline demographics, implicates task-profile differences -- specifically, nurses' more frequent postural transitions, patient handling, and heavy instrument transport -- as occupational determinants of injury severity [20].

Dose-Response Quantification: From Risk Factors to Risk Thresholds

The hierarchical regression results showing that the three exposure variables collectively explained 68.7% of pain variance -- compared to only 12.5% by demographics alone -- demonstrates that daily ergonomic exposures, rather than immutable personal characteristics, are the predominant drivers of musculoskeletal pain in the OR. This finding carries profound implications: it suggests that a substantial proportion of OR WMSDs burden is modifiable through organizational and ergonomic interventions rather than through individual-level strategies alone.

The dose-response coefficients provide the first quantitative benchmarks for OR occupational health management to our knowledge. An additional hour of awkward posture (β=0.45) inflicts approximately 40% more incremental damage than an additional hour of overtime (β=0.32), reaffirming ergonomic quality -- not merely work duration -- as the primary modifiable target [21]. The quartile threshold of ≥5.1 hours/day of awkward postures and ≥3.6

hours/day of overtime, both associated with VAS scores exceeding 7, provides concrete triggers for administrative controls: scheduling interventions to cap continuous awkward-posture time and cumulative overtime, rather than relying on discretionary rest, may be necessary to prevent crossing into moderate-to-severe pain.

Profession and Seniority as Effect Modifiers

The significantly stronger effect of awkward posture on pain in nurses versus surgeons (β=0.51 vs. 0.37, P=0.031) highlights a critical intervention gap. While surgeons maintain relatively fixed postures focused on the surgical field -- and can benefit from table height adjustment, ergonomic chairs, and foot pedals -- nurses must constantly transition between instrument tables, patient positioning, equipment retrieval, and supply management, often in suboptimal ergonomic conditions [22]. This finding challenges the common practice of pooling OR personnel in WMSDs studies and argues for profession-specific risk assessment and mitigation strategies.

The monotonic escalation of dose-response slopes with work seniority -- overtime effects ranging from β=0.25 (novice) to β=0.42 (>20 years) -- can be interpreted through two complementary mechanisms: (a) cumulative biomechanical wear and age-related degenerative changes in musculoskeletal tissues, which reduce tolerance to a given ergonomic load [23]; and (b) survivor bias, whereby senior staff continue working despite pre-existing conditions, rendering them more vulnerable to incremental exposures [24]. Regardless of mechanism, this finding underscores that senior OR staff, who often bear the heaviest clinical and teaching responsibilities, should be prioritized for workload reduction and enhanced protective measures, rather than assumed to be resilient by virtue of experience.

Body Composition: A Rapidly Modifiable Risk Marker

The significant deterioration of body composition over only four weeks -- with increases in body fat percentage and visceral fat level, and decreases in skeletal muscle mass -- is a novel finding that has not, to our knowledge, been reported in previous OR WMSDs literature. While the absolute changes appear modest (0.8% body fat increase, 0.3 kg muscle loss), their occurrence over such a short interval in otherwise healthy working adults is concerning. Mechanistically, elevated visceral adipose tissue is a known source of pro-inflammatory cytokines (TNF-α, IL-6) that can sensitize nociceptive pathways and exacerbate musculoskeletal pain [25], while reduced skeletal muscle mass compromises the passive and active stabilization of joints, increasing mechanical load on articular and ligamentous structures [14]. The significantly greater deterioration in nurses is consistent with their heavier physical workload and more limited opportunities for restorative exercise, and suggests that body composition surveillance and workplace-based exercise programs may serve as complementary strategies to ergonomic interventions.

Implications for Practice and Policy

Based on these findings, we propose a multi-level occupational health framework for OR WMSDs prevention:

At the organizational level, surgical scheduling should incorporate mandatory ergonomic breaks at intervals not exceeding 3-4 continuous hours of awkward posture. The cumulative daily overtime threshold (3.6 h) and posture threshold (5.1 h) identified in this study can serve as operational benchmarks for shift planning. Hospitals should invest in height-adjustable operating tables, anti-fatigue flooring, mechanical patient-lifting devices, and automated instrument-delivery systems to reduce the biomechanical load on OR staff.

At the professional level, differentiated protection strategies are warranted: for nurses, the focus should be on reducing posture variety burden (e.g., alternating between scrub and circulating roles) and minimizing solo heavy lifting; for senior staff (>20 years), workload reduction, more frequent health surveillance, and priority access to ergonomic aids should be implemented. Regular body composition assessment and workplace-based strength and conditioning programs -- particularly targeting core and lower-back musculature -- may mitigate the progressive physiological deterioration observed in this cohort.

At the individual level, OR staff should receive standardized ergonomics training covering correct lifting biomechanics, micro-stretching techniques, and self-monitoring of pain thresholds. A culture of proactive reporting should be cultivated, where early musculoskeletal symptoms are addressed before they escalate to sick leave or career attrition.

Limitations

Several limitations should be acknowledged. First, the sample size of 40 participants, although powered for the primary regression analyses, constrains the precision of subgroup estimates and limits generalizability to other hospital types, surgical specialties, and geographic regions. Second, the 4-week tracking period, while sufficient to capture weekly exposure-pain dynamics and short-term body composition changes, cannot address long-term WMSDs progression or recovery trajectories. Third, daily exposures were assessed through self-report rather than direct measurement (e.g., inertial measurement units for posture, observational time-motion analysis), introducing potential reporting bias, although the prospective daily-log design substantially mitigates recall bias compared to retrospective surveys. Fourth, although we controlled for key demographics, unmeasured confounders -- including psychosocial stressors, sleep quality, dietary patterns, and detailed task-mix composition -- may influence both

exposures and outcomes. Fifth, the 100% WMSDs prevalence limited our ability to compare those with versus without WMSDs; future studies with larger samples could examine dose-response across a broader severity spectrum including asymptomatic workers. Finally, the single-center design in a high-volume tertiary hospital limits external validity; multi-center studies spanning different hospital tiers and surgical volumes are needed.

Conclusions

This study provides the first prospective, quantitatively modeled evidence of dose-response relationships between dynamic daily work exposures and musculoskeletal pain among OR staff. Awkward posture duration, overtime hours, and heavy-lifting frequency each exhibit independent, graded associations with pain intensity, with identifiable exposure thresholds predictive of moderate-to-severe pain. Profession (nurse vs. surgeon) and work seniority significantly moderate these relationships, with nurses and senior staff showing heightened vulnerability. The rapid deterioration of body composition over four weeks of routine OR work highlights an under-recognized dimension of occupational health risk. These findings support a paradigm shift from generic, one-size-fits-all WMSDs prevention toward stratified, threshold-guided occupational health strategies tailored to profession, seniority, and individual physiological status.

References

1. da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. Am J Ind Med. 2010;53(3):285-323.

2. GBD 2021 Musculoskeletal Disorders Collaborators. Global, regional, and national burden of other musculoskeletal disorders, 1990-2021, and projections to 2050: a systematic analysis of the Global Burden of Disease Study 2021. Lancet Rheumatol. 2023;5(11):e670-82.

3. Davis KG, Kotowski SE. Prevalence of musculoskeletal disorders for nurses in hospitals, long-term care facilities, and home health care: a comprehensive review. Hum Factors. 2015;57(5):754-92.

4. Thinkhamrop W, Sawaengdee K, Tangcharoensathien V, et al. Burden of musculoskeletal disorders among registered nurses: evidence from the Thai nurse cohort. BMC Nurs. 2017;16:68.

5. Epstein S, Sparer EH, Tran BN, et al. Prevalence of work-related musculoskeletal disorders among surgeons and interventionalists: a systematic review and meta-analysis. JAMA Surg. 2018;153(2):e174947.

6. Szeto GP, Ho P, Ting AC, et al. Work-related musculoskeletal symptoms in surgeons. J Occup Rehabil. 2009;19(2):175-84.

7. AlQahtani SM, Alzahrani MM, Harvey EJ. Prevalence of musculoskeletal disorders among orthopedic trauma surgeons: an OTA survey. Can J Surg. 2016;59(1):42-7.

8. Liu SQ, Zhao SM, Li LX. Mental health status and influencing factors of occupational musculoskeletal disorders among operating room nurses. Occup Health. 2021;37(2):195-9. [in Chinese]

9. Bian J, Zhao LZ, Zhu XQ, et al. Meta-analysis of influencing factors of occupational musculoskeletal disorders among Chinese nurses. Occup Health. 2024;40(18):2564-8. [in Chinese]

10. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J Electromyogr Kinesiol. 2004;14(1):13-23.

11. Long MH, Bogossian FE, Johnston V. The prevalence of work-related neck, shoulder, and upper back musculoskeletal disorders among midwives, nurses, and physicians: a systematic review. Workplace Health Saf. 2013;61(5):223-9.

12. Abdalla DR, Freitas FS, Matheus JPC, et al. Postural biomechanical risks for nursing workers. Rev Bras Enferm. 2014;67(3):421-7.

13. Nussbaum MA, Torres N. Contemporary challenges and opportunities for ergonomics research in healthcare. IISE Trans Occup Ergon Hum Factors. 2020;8(4):169-74.

14. Visser M, Goodpaster BH, Kritchevsky SB, et al. Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. J Gerontol A Biol Sci Med Sci. 2005;60(3):324-33.

15. Steenland K, Deddens JA. A practical guide to dose-response analyses and risk assessment in occupational epidemiology. Epidemiology. 2004;15(1):63-70.

16. Yang L, Wang ZX, et al. Development and validation of the Nurse Occupational Musculoskeletal Disorders Questionnaire. Chin J Ind Hyg Occup Dis. 2002;20(4):274-7. [in Chinese]

17. Chalder T, Berelowitz G, Pawlikowska T, et al. Development of a fatigue scale. J Psychosom Res. 1993;37(2):147-53.

18. Dianat I, Bazazan A, Rastgoo L, et al. Work-related physical and psychosocial risk factors for musculoskeletal disorders in Iranian operating room nurses. Int J Occup Saf Ergon. 2019;25(4):557-64.

19. Nourollahi T, Ghaedi M, Razeghi M, et al. The prevalence of work-related musculoskeletal disorders among Iranian operating room personnel: a systematic review and meta-analysis. J Perianesth Nurs. 2022;37(3):365-73.

20. Clari M, Garzaro G, Di Maso M, et al. Upper limb work-related musculoskeletal disorders in operating room nurses: a multicenter cross-sectional study. Int J Environ Res Public Health. 2019;16(16):2844.

21. Waters TR, Dick RB. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. Rehabil Nurs. 2015;40(3):148-65.

22. Sheikhzadeh A, Gore C, Zuckerman JD, et al. Perioperating nurses and technicians' perceptions of ergonomic risk factors in the surgical environment. Appl Ergon. 2009;40(5):833-9.

23. Okunribido OO, Magnusson M, Pope MH. The role of whole body vibration, posture and manual materials handling as risk factors for low back pain in occupational drivers. Ergonomics. 2008;51(3):347-58.

24. Arvidsson I, Simonsen JG, Dahlqvist C, et al. Cross-sectional associations between occupational factors and musculoskeletal pain in women teachers, nurses and sonographers. BMC Musculoskelet Disord. 2016;17:35.

25. Franceschi C, Campisi J. Chronic inflammation (inflammaging) and its potential contribution to age-associated diseases. J Gerontol A Biol Sci Med Sci. 2014;69(Suppl 1):S4-9.

Table Captions

Table 1. Baseline demographic and occupational characteristics of participants (N=40).

Table 2. Prevalence of WMSDs and mean VAS pain scores by anatomical site (N=40).

Table 3. Comparison of daily work exposures between surgeons and nurses over 20 workdays.

Table 4. Body composition indices at baseline and after 4-week tracking (N=40).

Table 5. Hierarchical multiple linear regression of work exposures on daily VAS pain score (N=40).

Figure Caption

Figure 1. Dose-response gradients of daily VAS pain scores across quartiles of overtime hours (a), awkward posture duration (b), and heavy-lifting frequency (c). Error bars represent ±1 SD. All linear trends significant at $P<0.001$.

TABLES AND FIGURES

Figure 1. Dose-response gradients of daily VAS pain scores across quartiles of overtime hours (a), awkward posture duration (b), and heavy lifting frequency (c). Bars represent mean ± SD. The red dashed line indicates the threshold for severe pain (VAS = 7). Quartile cutoffs are displayed above each bar. All dose-response trends were significant (P < 0.001 by one-way ANOVA).

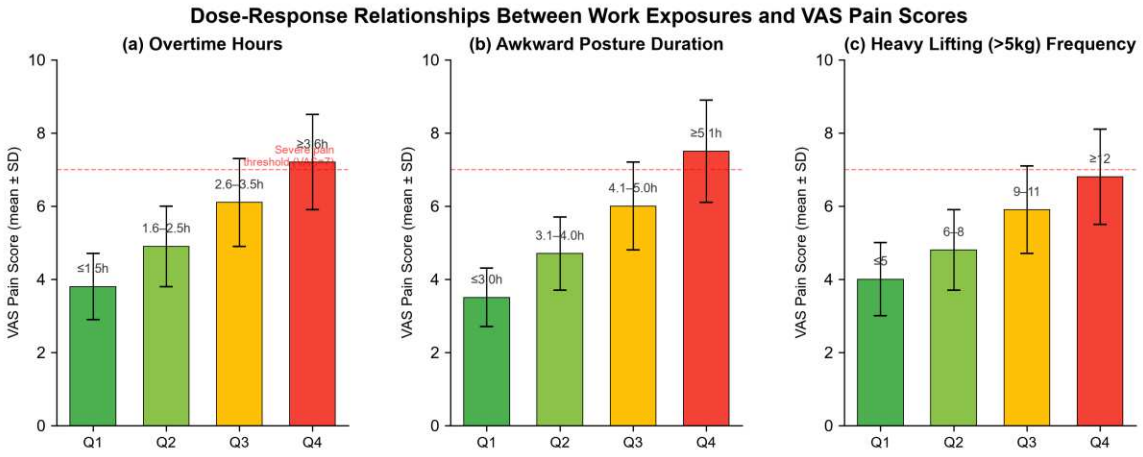


Table 1. Baseline demographic and occupational characteristics of participants (N=40).

Characteristic	Category	n	%
Gender	Male	8	20.0
	Female	32	80.0
Age (years)	26–35	21	52.5
	36–45	13	32.5
	≥46	6	15.0
Education	Bachelor's	32	80.0
	Master's or above	8	20.0
Occupation	Surgeon	20	50.0
	Nurse	20	50.0

Professional title	Junior	14	35.0
	Intermediate	16	40.0
	Senior	10	25.0
Work experience	1–5 years	14	35.0
	6–10 years	7	17.5
	11–20 years	9	22.5
	>20 years	10	25.0
Weekly work hours	40–49 h	6	15.0
	50–59 h	18	45.0
	60–69 h	12	30.0
	≥70 h	4	10.0
Shift work	Yes	33	82.5
	No	7	17.5
Self-rated health	Good	3	7.5
	Fair	34	85.0
	Poor	3	7.5
Post-work fatigue	Not tired	1	2.5
	Tired	30	75.0
	Very tired	9	22.5
Medical visit in 6 mo	Yes	8	20.0
	No	32	80.0
Exercise frequency	Never	15	37.5
	1–2 times/week	20	50.0
	≥3 times/week	5	12.5
Age (years), mean ± SD		37.0 ± 7.2	

Weekly work hours, mean ± SD	57.4 ± 9.0
Commute time (min), mean ± SD	30.5 ± 17.0

Table 2. Prevalence of WMSDs and mean VAS pain scores by anatomical site (N=40).

Anatomical site	Lifetime prevalence n (%)	Past-week VAS mean ± SD	Sick leave due to pain n (%)
Neck	40 (100.0)	5.8 ± 1.7	35 (87.5)
Shoulder	40 (100.0)	5.5 ± 1.6	32 (80.0)
Upper back	40 (100.0)	5.2 ± 1.5	28 (70.0)
Elbow	38 (95.0)	4.3 ± 1.4	15 (37.5)
Lower back	40 (100.0)	6.2 ± 1.8	38 (95.0)
Wrist/hand	40 (100.0)	5.1 ± 1.5	25 (62.5)
Hip/buttock	40 (100.0)	4.7 ± 1.4	18 (45.0)
Knee	40 (100.0)	4.9 ± 1.5	22 (55.0)
Ankle/foot	40 (100.0)	4.5 ± 1.4	16 (40.0)
Overall mean	—	**5.1 ± 1.3**	—

Note: All 40 participants took sick leave due to WMSDs: 1–3 days (30.0%), 4–7 days (45.0%), 8–14 days (17.5%), ≥15 days (7.5%). Nurses had significantly longer sick leave (6.8 ± 3.2 vs. 4.5 ± 2.7 days, P = 0.019) and higher overall VAS (5.5 ± 1.4 vs. 4.7 ± 1.2, P = 0.049) than surgeons.

Table 3. Comparison of daily work exposures between surgeons and nurses over 20 workdays.

Exposure variable	Total (N=40) mean ± SD	Surgeons (n=20) mean ± SD	Nurses (n=20) mean ± SD	t	P
Daily overtime (h)	2.5 ± 1.2	2.2 ± 1.0	2.8 ± 1.3	1.672	0.103
Daily awkward posture duration (h)	4.2 ± 1.5	3.5 ± 1.2	4.9 ± 1.6	3.021	0.004

Daily heavy lifting (>5 kg) frequency	8.5 ± 3.2	6.8 ± 2.5	10.2 ± 3.4	3.765	0.001

Abbreviations: SD, standard deviation. P-values from independent-samples t-test. Bold P-values indicate statistical significance (P < 0.05).

Table 4. Body composition indices at baseline and after 4-week tracking (N=40).

Body composition index	Baseline mean ± SD	After 4 weeks mean ± SD	Change	t	P
Body weight (kg)	60.2 ± 8.5	60.6 ± 8.7	+0.4	2.345	0.024
Skeletal muscle mass (kg)	24.3 ± 4.2	24.0 ± 4.1	−0.3	2.178	0.036
Body fat mass (kg)	18.5 ± 5.7	19.1 ± 5.9	+0.6	2.567	0.014
Body fat percentage (%)	30.7 ± 5.2	31.5 ± 5.4	+0.8	2.789	0.008
BMI (kg/m²)	22.8 ± 2.5	23.0 ± 2.6	+0.2	1.987	0.054
Waist-hip ratio	0.86 ± 0.07	0.87 ± 0.07	+0.01	1.876	0.068
Visceral fat level	7.8 ± 2.5	8.1 ± 2.6	+0.3	2.013	0.049
Basal metabolic rate (kcal)	1325 ± 126	1312 ± 123	−13	2.234	0.031
Lower limb muscle grade	8.2 ± 1.5	8.1 ± 1.5	−0.1	1.765	0.086

Note: Nurses showed significantly greater deterioration than surgeons: Δbody fat percentage (+1.1 ± 0.5% vs. +0.5 ± 0.4%, P < 0.001), Δskeletal muscle mass (−0.4 ± 0.2 kg vs. −0.2 ± 0.1 kg, P = 0.001).

Table 5. Hierarchical multiple linear regression of work exposures on daily VAS pain score (N=40).

Variable	B	SE	β	t	P	R²	Adj. R²	ΔR²	F	P (model)

Model 1						**0.125**	**0.087**	**—**	**3.267**	**0.023**
Age	0.021	0.015	0.187	1.400	0.170					
Gender (female vs. male)	0.152	0.234	0.089	0.650	0.520					
Work experience (years)	0.035	0.018	0.268	1.944	0.059					
Professional title	−0.087	0.125	−0.098	−0.696	0.490					
Model 2						**0.687**	**0.652**	**0.562**	**19.654**	**<0.001**
Age	0.012	0.010	0.107	1.200	0.238					
Gender (female vs. male)	0.089	0.156	0.052	0.571	0.571					
Work experience (years)	0.023	0.012	0.176	1.917	0.063					
Professional title	−0.056	0.083	−0.063	−0.675	0.504					
Daily overtime (h)	0.321	0.078	0.320	4.115	<0.001					
Daily awkward posture (h)	0.452	0.085	0.450	5.318	<0.001					

Daily heavy lifting (>5 kg)	0.278	0.069	0.275	4.029	<0.001

Abbreviations: B, unstandardized coefficient; SE, standard error; β, standardized coefficient; Adj. R^2, adjusted R-squared; ΔR^2, change in R-squared from Model 1. Model 1 included baseline covariates only; Model 2 added three work exposure variables. Dependent variable: daily VAS pain score (0–10). Bold P-values indicate statistical significance ($P < 0.05$).