

Dose-dependent impairment of postoperative recovery by perioperative poor sleep: a threshold of two or more nights in Chinese orthopedic surgical patients (a prospective observational cohort study)

Cheng Xu

Renmin Hospital of Wuhan University

Wei Wang

Renmin Hospital of Wuhan University

Yayi Huang

Renmin Hospital of Wuhan University

Linghua Tang

Renmin Hospital of Wuhan University

Zhigang Liu

Renmin Hospital of Wuhan University

Jiabao Hou

Renmin Hospital of Wuhan University

Wenqin Song

rm-swq@whu.edu.cn

Renmin Hospital of Wuhan University

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Abstract

Background

Poor sleep is common after surgery but is usually treated as a binary exposure, which obscures whether isolated nights carry the same prognostic weight as sustained disturbance. We examined whether the number of nights of perioperative poor sleep is associated with recovery quality after orthopedic surgery in a dose-dependent manner.

Methods

In this prospective observational cohort study, 271 adults undergoing elective orthopedic surgery completed the St Mary's Hospital Sleep Questionnaire (SMHSQ) and a modified 9-item QoR-15 scale (range 0–90) on the day before surgery (-D1) and on postoperative days 1–3. Patients were grouped by the number of nights of poor sleep (0, 1, or ≥ 2). Risk factors were identified by multivariable logistic regression and QoR-15 scores compared by one-way ANOVA with post-hoc pairwise comparisons.

Results

Poor sleep occurred in 73.4% (199/271) of patients. Independent risk factors were usual sleep quality ($p = 0.011$), duration of surgery (OR 1.42, 95% CI 1.06–1.91; $p = 0.020$) and moderate pain (OR 1.31, 95% CI 1.08–1.58; $p = 0.005$); anxiety showed a trend (OR 1.37, 95% CI 0.96–1.96; $p = 0.086$). Compared with group A, group C had greater decrements in total QoR-15 score on days 1–3 after surgery (5.8, 8.6 and 5.9 points; $p = 0.005$, $p < 0.001$ and $p = 0.005$), with selective deficits in respiration, appetite and vigor, whereas group B differed from group A on days 1–2 after surgery ($p = 0.018$ and $p = 0.016$); the decrement increased linearly with exposure category ($p \leq 0.008$ for trend).

Conclusions

Perioperative poor sleep is highly prevalent and impairs recovery in a dose-dependent manner. Two or more nights—a modifiable threshold—produced deficits persisting through postoperative day 3, whereas a single night produced smaller deficits confined to the first two days; this threshold can guide sleep screening.

Trial registration

Chinese Clinical Trial Registry, ChiCTR1900023756. Registered 10 June 2019.

Novelty statement

This is the first study to treat perioperative poor sleep as a graded exposure in orthopedic surgery, defining a threshold of two or more nights for clinically meaningful impairment of recovery.

Background

Sleep is a fundamental pillar of health, and sleep deprivation has been described as a major unmet public health problem [1]. Its disruption is increasingly recognized as a prevalent yet under-addressed perioperative issue. Sleep disturbances persist for days after surgery in a considerable number of patients. Even with fast-track protocols for hip and knee arthroplasty, significant sleep impairment is observed postoperatively, and non-cardiac surgery is frequently associated with multifactorial sleep disruption [2, 3]. A recent systematic review and meta-analysis estimated that sleep disturbances affect a large proportion of surgical patients and identified both preoperative and postoperative risk factors [4, 5].

The perioperative period is uniquely hostile to sleep. Surgical trauma, postoperative pain, psychological stress and anxiety, environmental factors (noise, light, monitoring), and perioperative analgesics all conspire to disrupt sleep [3, 6–8]. Poor sleep is not merely a comfort issue—it is mechanistically linked to worse outcomes. Clinical and experimental evidence links sleep loss to heightened pain sensitivity [6, 9], impaired cognition and postoperative neurocognitive disorders [10, 11], low-grade inflammation [12], and delayed recovery [8]. Bidirectional relationships between pain and sleep are well described [13], as are links between preoperative anxiety and both sleep disturbance and adverse postoperative outcomes [8, 14].

Sleep quality in surgical cohorts is most often captured with validated questionnaires such as the St Mary's Hospital Sleep Questionnaire [15], whereas recovery is increasingly quantified using patient-reported quality-of-recovery tools such as the QoR-15 [16]. Although impaired sleep and its association with recovery have been examined in selected populations—including arthroplasty and other surgical groups [2, 5, 6, 7, 11]—the evidence base is heterogeneous and derives largely from Western or single-procedure cohorts. Data describing the prevalence, risk factors, and recovery impact of poor sleep quality specifically in patients undergoing elective orthopedic surgery, and using a combination of a validated sleep questionnaire and the QoR-15, remain limited.

One gap, however, limits the translational value of this evidence: sleep quality is almost universally treated as a binary exposure—'good' versus 'poor'—which obscures whether recovery impairment scales with the number of disrupted nights. Whether a single disturbed night carries the same prognostic weight as several consecutive nights is unknown, yet the distinction determines precisely when perioperative sleep support should be initiated. Grading the exposure by the count of poor nights may therefore reveal an actionable threshold for intervention.

Accordingly, this prospective observational study enrolled consecutive patients undergoing elective orthopedic surgery—spanning spinal, upper-limb, and lower-limb/hip procedures—and assessed sleep quality with the St Mary's Hospital Sleep Questionnaire across four perioperative time points (–D1, D1, D2, D3), together with repeated QoR-15 recovery measurement. Rather than dichotomizing sleep, we stratified patients into good sleep (group A), a single night of poor sleep (group B), and two or more nights of poor sleep (group C) to test for a dose–response in recovery impairment. We aimed to (1)

determine the prevalence of poor perioperative sleep quality, (2) identify independent risk factors for poor sleep quality, and (3) define the exposure threshold at which postoperative recovery, measured by the QoR-15, is significantly impaired.

Methods

Design

A prospective observational cohort study was conducted by consecutively enrolling patients undergoing orthopedic surgery between July 2019 and February 2020. The study was approved by the Ethics Committee of Renmin Hospital of Wuhan University (2018K-C073) and was prospectively registered with the Chinese Clinical Trial Registry (ChiCTR1900023756) on 10 June 2019, before the first patient was enrolled. Patients provided written and oral informed consent prior to participating.

Subjects

Patients older than 18 years that underwent orthopedic surgery and were administered general anesthesia, spinal anesthesia or nerve block anesthesia at the Department of Anesthesiology, Renmin Hospital of Wuhan University were initially selected. After excluding patients with psychological and neurological diseases, hyperthyroidism, hypothyroidism, history of opioids, anti-anxiety or other sleep influencing drugs, and hearing, vision and speech problems, 400 patients who were anesthetized by attending anesthesiologists were enrolled (Fig. 1). In addition, 104 patients refused to answer the questionnaires, 22 withdrew, and 3 were scheduled for ICU admission, leaving 271 patients who were finally selected for the study.

Data collection

Patients were interviewed and asked to provide written informed consent one day before surgery. Demographic data, Quality of Recovery-15 (QoR-15), and St Mary's Sleep Questionnaire (SMHSQ) results were collected one day before surgery (-D1) and on postoperative days 1, 2, and 3 (D1, D2, and D3, respectively). The QoR-15 questionnaire evaluates postoperative recovery in terms of breathing, appetite, energy, sleep, mobility, communication, comfort, pain, nausea, anxiety, and emotional state [16]. Six of the 15 items were not included in the composite score. Items 5 (independent personal hygiene and toileting), 6 (communication with family or friends) and 7 (support from doctors and nurses) were not applicable to patients confined to bed in the early postoperative period after orthopedic surgery. Item 4 (sleep quality) was omitted because sleep was characterised in detail with the SMHSQ and retaining it would have made the exposure and the outcome share the same construct. Items 11 and 12 (moderate and severe pain) were omitted because pain was graded separately and entered into the regression models as an independent predictor. Nine items were therefore scored at each time point (breathing, appetite, energy, return to work or usual activities, feeling comfortable and in control, general well-being,

nausea and vomiting, worry and anxiety, and sadness and depression), giving a total score of 0–90; this modified 9-item score is referred to as the QoR-15 score throughout. The SMHSQ evaluates sleep quality during the preceding 24 hours in terms of sleep efficiency, total sleep duration, sleep onset latency, fragmented sleep, nocturnal and daytime sleep hours, depth and satisfaction of sleep, clarity upon awakening, and number of nocturnal awakenings [15]. Acute insomnia has been conceptualized as a short-term, stress-precipitated sleep difficulty that is increasingly recognized as a distinct phenotype and a risk factor for chronic insomnia [17]. However, there is no gold standard for identifying poor sleep quality among hospitalized patients. Based on previously published data, we defined poor sleep quality by any of the following criteria: (1) dissatisfactory sleep quality or quantity, (2) light depth of sleep, waking up more than three times after sleep onset, early morning awakening, or prolonged sleep onset latency, or (3) total sleep duration shorter than six hours. According to these criteria and SMHSQ scores, patients were divided into three groups: good sleep quality (group A), one night with poor sleep quality (group B), and more than one night with poor sleep quality (group C). QoR-15 scores at -D1, D1, D2, and D3 were compared across these groups. Furthermore, the duration and type of surgery, type of anesthesia and any drugs used were recorded during the perioperative period.

Data analysis

Sleep disturbance has been reported in 60% (95% CI 50–69%) of surgical patients before operation [4]. For assumed perioperative prevalences of 60–70%, estimating the prevalence with a 95% CI half-width of ± 5 percentage points requires between 323 and 369 patients; the protocol therefore pre-specified 400 patients, a margin of 8% over the most conservative assumption, which also absorbed incomplete questionnaires.

All analyses were performed using IBM SPSS 22. Continuous variables are presented as mean $\pm$ SD and compared between groups using t-tests or Mann–Whitney U tests depending on the distribution of the data; categorical variables are presented as n (%) and compared using the chi-square test. Perioperative sleep quality was analysed in two ways. For the risk-factor analysis, patients were dichotomised into good versus poor sleep quality, and this binary outcome was used as the dependent variable; variables with $p < 0.2$ in univariable analysis were considered into a multivariable logistic regression model. The graded A/B/C exposure was used only for the dose–response analysis of QoR-15 recovery. Comparisons across the three groups were made using one-way ANOVA and Welch's ANOVA, with Tamhane's T2 test for post-hoc pairwise comparisons (Tukey's HSD as a sensitivity analysis). Dose–response relationships were assessed using a linear contrast ($-1, 0, +1$) and a linear trend test with exposure coded 0, 1 and 2. Pre-specified interactions were tested using likelihood-ratio tests.

Seven patients (2.6%; three in group A, one in group B and three in group C) lacked day-3 questionnaire data; because this proportion was below 5% and was similarly distributed across exposure groups, the corresponding item scores were replaced by the dimension-specific day-3 mean. Gender ($p = 0.63$) and comorbidity ($p = 0.67$) were not independently associated with the outcome when added to this model (joint likelihood-ratio test $\chi^2 = 0.41$, $df = 2$, $p = 0.82$), the intraoperative doses of the six anaesthetic

agents (sufentanil, remifentanil, dexmedetomidine, propofol, sevoflurane and midazolam) were correlated with the duration of surgery ($r = 0.10-0.60$) and were non-significant when added to the model (all $p > 0.45$; joint $\chi^2 = 0.64$, $p = 0.996$); these variables were therefore not retained. Age was retained as a pre-specified covariate because interactions with age were tested.

Results

Demographic characteristics of the patients

The demographic characteristics of the patients are summarized in Table 1. A total of 400 patients were recruited, of whom 104 declined to answer the questionnaires, 22 withdrew, and 3 were scheduled for ICU admission and thus excluded. The remaining 271 patients included 141 men and 130 women with mean age 52.9 ± 16.1 years and range 18–90 years. The mean BMI of the patients was 24.1 ± 3.6 (14.6–40). Nineteen patients (7%) did not have any educational training, whereas 51 (18.8%), 144 (53.1%) and 57 (21%) patients had < 6 years, 6–12 years and > 12 years of education respectively. Furthermore, 99 (36.5%) patients had a history of hypertension, diabetes, heart disease, renal disease, rib fracture, or chronic pulmonary disease, among others, 65 (24%) were smokers, and 65 (24%) consumed alcohol. Spinal surgery was performed in 75 (27.7%) patients, whereas 39 (14.4%) underwent arm, shoulder, or clavicle surgery, and 157 (57.9%) underwent leg or hip surgery. In addition, 217 (80.1%) patients underwent general anesthesia, 34 (12.5%) received combined nerve block and general anesthesia, and 20 (7.4%) received either nerve block or intraspinal anesthesia. Good sleep quality was reported by 72 (26.6%) patients, whereas 102 (37.6%) experienced one night, 67 (24.7%) experienced two nights, 21 (7.7%) experienced three nights, and 9 (3.3%) experienced four nights of poor sleep. In addition, most patients experienced poor sleep on the first (119; 43.9%) and second (96; 35.4%) night after surgery, while only 55 (20.3%) patients slept poorly prior to the surgery and 65 (24%) experienced poor sleep on the third night after surgery.

Table 1
Demographic and perioperative characteristics of the patients (n = 271)

Items	Value
Age (years)	52.9 ± 16.1
Gender (Male/Female)	141/130
BMI	24.1 ± 3.6
Education background	
0 years (%)	19 (7.0)
< 6 years (%)	51 (18.8)
6–12 years (%)	144 (53.1)
> 12 years (%)	57 (21.0)
Complicated with other disease (%)	99 (36.5)
Smoke (%)	65 (24)
Alcohol (%)	65 (24)
Surgery type	
Spine surgery (%)	75 (27.7)
Arm/shoulder/clavicle surgery (%)	39 (14.4)
Leg/hip surgery (%)	157 (57.9)
Anesthesia type	
General anesthesia (%)	217 (80.1)
Nerve block and general anesthesia (%)	34 (12.5)
Nerve block/intraspinal anesthesia (%)	20 (7.4)
Good sleep quality (%)	72 (26.6)
One night poor sleep quality (%)	102 (37.6)
Two nights poor sleep quality (%)	67 (24.7)
Three nights poor sleep quality (%)	21 (7.7)
Four nights poor sleep quality (%)	9 (3.3)
Poor sleep quality the night before surgery (%)	55 (20.3)
NOTE: Data are presented as the mean ± SD or as the number and ratio of patients (%). BMI, body mass index.	

Items	Value
Poor sleep quality first night after surgery (%)	119 (43.9)
Poor sleep quality second night after surgery (%)	96 (35.4)
Poor sleep quality third night after surgery (%)	65 (24.0)
NOTE: Data are presented as the mean $\pm$ SD or as the number and ratio of patients (%). BMI, body mass index.	

Baseline (preoperative) recovery scores were not balanced across the three groups (70.6 ± 7.2 in group A, 67.2 ± 11.0 in group B and 65.7 ± 11.8 in group C; $F(2, 268) = 4.62, p = 0.011$), the largest differences being in the energy ($p = 0.001$) and emotional-control ($p < 0.001$) items. The within-subject change from each patient's own baseline was therefore used as the primary measure of recovery.

Potential risk factors of poor sleep quality

Univariate analysis was performed to identify the potential risk factors of poor sleep quality during the perioperative period (Table 2). Significantly more female patients reported poor as opposed to good sleep quality ($p = 0.038$). In addition, usual sleep quality ($p = 0.008$), duration of surgery ($p = 0.004$), moderate and severe pain ($p < 0.001$), nausea ($p = 0.006$), anxiety ($p = 0.001$) and sadness ($p = 0.011$) all differed significantly between the two groups (Table 2). The binary classification used here (poor perioperative sleep corresponds to groups B and C combined) is defined in Methods.

Table 2
Univariate analysis of risk factors for poor sleep quality

Variable(n = 271)	Good sleep quality group	Poor sleep quality group	P value
Age	51.7 ± 15.8	53.4 ± 16.2	0.460
Gender(M/F)	45/27	96/103	0.038
BMI	24.4 ± 3.3	23.9 ± 3.8	0.326
Education			0.544
0 years(%)	5(6.9)	14(7.0)	
< 6years(%)	11(15.3)	40(20.1)	
6–12years(%)	38(52.8)	106(53.3)	
> 12year(%)	18(25)	39(19)	
Usual sleep quality			0.008
Bad sleep quality	6(8.3)	32(16.1)	
Average sleep quality	24(33.3)	92(46.2)	
Good sleep quality	42(58.3)	75(37.7)	
Complicated with other Disease(yes/no)	21/51	78/121	0.131
Smoke(yes/no)	14/58	51/148	0.294
Alcohol(yes/no)	15/57	50/149	0.467
Type of surgery			0.380
Spine surgery(%)	22(30.6)	53(26.6)	
Arm/shoulder/clavicle Surgery(%)	13(18.1)	26(13.1)	
Leg/hip surgery(%)	37(51.4)	120(60.3)	
Type of anesthesia			0.115
General anesthesia(%)	59(81.9)	158(79.4)	
Nerve block and general anesthesia(%)	5(6.9)	29(14.6)	
Nerve block/intraspinal anesthesia(%)	8(11.1)	12(6.0)	
Duration of surgery	1.8 ± 0.9	2.3 ± 1.4	0.004
NOTE: Data are presented as the mean ± SD or as the number and ratio of patients (%). M,male, F, female; BMI, body mass index.			

Variable(n = 271)	Good sleep quality group	Poor sleep quality group	P value
Sufentanil (µg)	21.1 ± 10.1	23.5 ± 11.0	0.111
Remifentanil (µg)	681.3 ± 485.0	886.4 ± 1052.8	0.113
Dexmedetomidine (µg)	20.1 ± 32.0	23.6 ± 34.0	0.454
Propofol (mg)	249.3 ± 263.1	307.5 ± 353.5	0.203
Sevoflurane (ml)	11.5 ± 8.7	14.2 ± 11.4	0.071
Hypotension(%)	16(22.2)	44(22.1)	0.984
Moderate pain	1.45 ± 1.72	2.96 ± 2.40	< 0.001
Severe pain	0.30 ± 0.65	0.95 ± 1.27	< 0.001
Nausea	0.17 ± 0.42	0.43 ± 0.77	0.006
Anxiety	0.55 ± 0.97	1.23 ± 1.67	0.001
Sadness	0.31 ± 0.83	0.78 ± 1.48	0.011
NOTE: Data are presented as the mean ± SD or as the number and ratio of patients (%). M,male, F, female; BMI, body mass index.			

Clinical significance of poor sleep quality

Logistic analysis revealed that usual sleep quality ($p = 0.011$), duration of surgery (OR 1.42, 95% CI 1.06–1.91, $p = 0.020$) and moderate pain (OR 1.31, 95% CI 1.08–1.58, $p = 0.005$) were significant risk factors for poor sleep quality. Severe pain was not independently associated with poor sleep quality (OR 1.38, 95% CI 0.86–2.22, $p = 0.182$), and anxiety showed a trend toward significance (OR 1.37, 95% CI 0.96–1.96, $p = 0.086$). Perioperative anxiety is common in Chinese surgical patients and has been linked to adverse pre- and postoperative outcomes in a large multicentre survey [24]. Nausea and type of anaesthesia were not significantly associated with sleep quality during the perioperative period (Table 3). Sadness (OR 1.01, 95% CI 0.66–1.55, $p = 0.975$) and age (OR 0.99 per year, 95% CI 0.97–1.01, $p = 0.392$) were also not associated with poor sleep quality. None of the pre-specified interactions reached statistical significance: usual sleep quality × age ($p = 0.121$), moderate pain × type of anaesthesia ($p = 0.059$), severe pain × type of anaesthesia ($p = 0.261$), moderate pain × sadness ($p = 0.618$) and severe pain × sadness ($p = 0.425$); the interaction block as a whole was also non-significant ($\chi^2 = 11.24$, $df = 8$, $p = 0.189$). The odds ratios above are therefore interpreted as main effects.

Table 3
logistic analysis of risk factors for poor sleep quality

Variable(n = 271)	P value	OR(95% CI)
Usual sleep quality	0.011	
Good sleep quality VS Bad sleep quality	0.074	0.38(0.13–1.10)
Average sleep quality VS Bad sleep quality	0.956	0.97(0.33–2.84)
Type of anesthesia	0.299	
General anesthesia VS intraspinal/nerve block anesthesia	0.748	1.19(0.41–3.46)
Nerve block and general anesthesia VS intraspinal/nerve block anesthesia	0.193	2.57(0.62–10.70)
Duration of the surgery	0.020	1.42(1.06–1.91)
Moderate pain	0.005	1.31(1.08–1.58)
Severe pain	0.182	1.38(0.86–2.22)
Nausea	0.142	1.59(0.86–2.94)
Anxiety	0.086	1.37(0.96–1.96)
Sadness	0.975	1.01(0.66–1.55)
Age (years)	0.392	0.99(0.97–1.01)
Usual sleep quality * age	0.121	
Moderate pain * type of anesthesia	0.059	
Severe pain * type of anesthesia	0.261	
Moderate pain * sadness	0.618	
Severe pain * sadness	0.425	
NOTE: OR, odds ratio; CI, confidence interval.		

The effect of poor sleep quality on recovery

Compared to group A, group C showed a greater decrease in respiration scores at D2 (mean difference 0.97 points, $p = 0.017$, Fig. 2A), appetite scores at D1, D2 and D3 (1.72, 1.39 and 1.13 points; $p < 0.001$, $p = 0.0011$ and $p = 0.0016$, Fig. 2B), and vigor scores at D1, D2 and D3 (0.99, 1.60 and 1.14 points; $p = 0.044$, $p < 0.001$ and $p = 0.0066$, Fig. 2C). The decrease in appetite scores in group C was also greater than that in group B at D3 ($p = 0.033$, Fig. 2B). Consistent with this, the recovery change scores differed significantly across the three groups at all three time points (one-way ANOVA: $F(2,268) = 4.34$, 9.29 and 5.03; $p = 0.014$, $p < 0.001$ and $p = 0.007$ for D1, D2 and D3, respectively; Welch $F = 6.90$, 11.28 and 5.16; p

= 0.001, $p < 0.001$ and $p = 0.007$). Compared with group A, group C showed a significantly larger decrement at every time point (mean difference 5.84, 8.57 and 5.91 points; $p = 0.005$, $p < 0.001$ and $p = 0.005$ by Tamhane's T2 test), and group B did so on D1 and D2 (5.07 and 4.56 points; $p = 0.018$ and $p = 0.016$). Differences between groups C and B were smaller (0.78, 4.02 and 4.09 points) and did not remain significant after correction for multiple comparisons ($p = 0.977$, 0.130 and 0.101 by Tamhane's T2 test; $p = 0.914$, 0.071 and 0.059 by Tukey's HSD). Across the ordered exposure categories the decrement increased linearly with the number of poor-sleep nights (2.80, 4.27 and 3.02 points per exposure level; $p = 0.008$, $p < 0.001$ and $p = 0.002$ for trend). In contrast, work-recovery, sadness and anxiety scores did not differ significantly between groups at any time point (Fig. 2D-F).

Discussion

Sleep disorder is a frequent and clinically important complication of surgery and is associated with impaired recovery during the perioperative period [3, 4, 6, 10, 11, 13]. In our cohort of 271 patients undergoing elective orthopedic surgery, 73.4% experienced poor sleep quality, most often restricted to the first or second postoperative night—a pattern consistent with reports that sleep disruption affects the majority of surgical patients and is most pronounced on the initial postoperative night [4, 18]. Poor sleep affects recovery in a dose-dependent way, as shown by our results. On postoperative days 2–3, patients with two or more nights of poor sleep had lower overall QoR-15 scores than those with only one such night, although this difference did not remain significant after correction for multiple comparisons; their recovery stayed significantly below that of good-sleep patients through day 3, and the deficit increased linearly with the number of poor-sleep nights. This threshold—broadly, that one bad night is tolerated but two or more are not—has, to our knowledge, not been quantified through graded sleep-exposure stratification in orthopedic cohorts, and provides an actionable trigger for perioperative sleep monitoring and intervention.

The type of anesthesia or surgery did not independently predict perioperative sleep quality in our study. Although regional techniques are less invasive than general anesthesia, they can still disrupt sleep architecture; for example, rapid eye movement sleep is reduced on the first night after regional anesthesia and recovers by the fifth night [19]. In our cohort, however, only a small proportion of patients received regional or neuraxial anesthesia, limiting our ability to draw firm conclusions about technique-specific effects.

It is well recognized that baseline preoperative sleep quality is the strongest predictor of perioperative sleep disturbance, with preexisting sleep impairment predisposing patients to greater postoperative sleep disruption [4, 20]. In line with this framework, female sex was associated with poor perioperative sleep quality in our univariate analysis ($p = 0.038$), although it did not remain an independent predictor after multivariable adjustment; consistent with this, a systematic review and meta-analysis of surgical patients identified pre-existing sleep impairment and anxiety, rather than sex, as the risk factors for postoperative sleep disturbance [4].

Although poor sleep is widely linked to worse recovery [11, 20–22], whether all sleep disturbances carry the same prognostic weight remains uncertain. Our results show a dose-dependent effect: patients with two or more nights of poor sleep had significantly lower QoR-15 scores than good-sleep patients across the first three postoperative days and greater impairment in appetite, vigor, and respiration, whereas a single poor night produced smaller, intermediate deficits that were significant only on the first two days. This graded pattern indicates that the cumulative number of disrupted nights, rather than the mere occurrence of any single episode, drives clinically meaningful recovery impairment.

By pairing a sleep-specific instrument (the St Mary's Hospital Sleep Questionnaire, capturing efficiency, latency, depth, and awakenings) with a recovery-specific instrument (the QoR-15) and repeating both across four perioperative time points, the study yields a finer characterization of the sleep–recovery relationship than single-instrument or single-timepoint designs. Our mixed orthopedic cohort—comprising spinal (27.7%), upper-limb (14.4%), and lower-limb/hip (57.9%) procedures—extends the evidence beyond the single-procedure cohorts that dominate the field: prior orthopedic sleep work has centered on total knee arthroplasty [2], or lumbar fusion [23], or shoulder arthroplasty/rotator cuff repair [25, 26], and the only large Chinese cohort to date examined sleep across mixed (non-orthopedic-specific) surgical specialties using different instruments [20]. The repeated-measures design additionally captured the early postoperative trajectory, in which recovery impairment peaked on the first two postoperative days and persisted through postoperative day 3 among patients with two or more nights of poor sleep, matching the clinical impression that the first two nights represent the window of greatest disruption.

Several limitations should be acknowledged. First, sleep quality was assessed with questionnaires rather than polysomnography, which was not feasible owing to resource constraints. Second, the small number of patients receiving regional/neuraxial anesthesia precluded robust comparison of anesthetic techniques. Third, baseline recovery scores were not balanced across exposure groups, and patients entering surgery in a poorer state were more likely to experience poor postoperative sleep; although we analysed within-subject change scores to allow for this, we did not adjust for the baseline score in an analysis-of-covariance model, and reverse causation—poorer preoperative status predisposing to disturbed sleep rather than the converse—cannot be excluded. Fourth, as a single-center study of orthopedic patients, our findings may not generalize to other surgical populations. Finally, we did not measure inflammatory mediators. While anxiety, tissue injury, and pain are recognized triggers of pro-inflammatory signalling which can disrupt sleep architecture [27, 28], the direct mechanistic link underlying this relationship remains to be established. In addition, we analysed a modified 9-item version of the QoR-15 (score range 0–90) rather than the full 15-item instrument, because items requiring mobility or self-care were not applicable to patients confined to bed after orthopedic surgery. Myles et al. originally established an MCID of 8 points for the QoR-15-1, which was subsequently revised to 6 points–10 [29, 30] but cannot be extrapolated directly to our shortened version, so the clinical importance of the differences reported here should be interpreted with caution. Two of the retained items (worry/anxiety and sadness/depression) overlap with a candidate risk factor and with mood, potentially inflating the observed associations, and a sensitivity analysis excluding them is warranted; conversely, the sleep item

of the original scale, which would have overlapped most directly with our exposure, was not administered. The study was exploratory: the sample size was determined by the precision-based prevalence calculation described in Methods rather than by a power calculation for the recovery outcome, and although the achieved sample was sensitive to differences of approximately 5.0–5.4 points on the 0–90 modified scale (derived from the variability observed in this cohort), the wide confidence interval for severe pain indicates limited precision for that estimate. In addition, attrition from the 400 enrolled patients to the 271 analysed patients was not examined with a formal missing-data analysis.

Conclusions

Poor perioperative sleep quality is prevalent among Chinese patients undergoing orthopedic surgery, and is associated with usual sleep quality, duration of surgery and moderate pain, with anxiety showing a trend toward significance. Critically, recovery impairment was dose dependent: two or more nights of poor sleep produced deficits that persisted through the third postoperative day, whereas a single night produced smaller deficits confined to the first two postoperative days—a threshold that can guide perioperative sleep screening. Baseline sleep quality, longer duration of surgery, and postoperative pain are key modifiable risk factors, while anxiety warrants further study. Routine screening for sleep disturbance and targeted interventions to improve sleep may enhance postoperative recovery.

List of abbreviations

ANOVA, analysis of variance;

BMI, body mass index;

CI, confidence interval;

-D1, preoperative day 1 (one day before surgery);

D1, D2, D3, postoperative days 1, 2 and 3;

OR, odds ratio;

QoR-15, 15-item Quality of Recovery scale;

SD, standard deviation;

SMHSQ, St Mary's Hospital Sleep Questionnaire.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Renmin Hospital of Wuhan University on 9 October 2018 (approval No. 2018K-C073) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants before enrolment.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CX: data curation, writing - original draft, funding acquisition. WW: methodology, data curation. YH: investigation, data curation. LT: investigation, formal analysis. ZL: visualization. JH: writing - review & editing. WS: conceptualization, supervision, funding acquisition. All authors read and approved the final manuscript.

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Use of artificial intelligence tools

A large language model was used solely for language editing of the manuscript text. No data, analyses, results or scientific content were generated by the tool. All text was reviewed and verified by the authors, who take full responsibility for the content of the manuscript.

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Figures

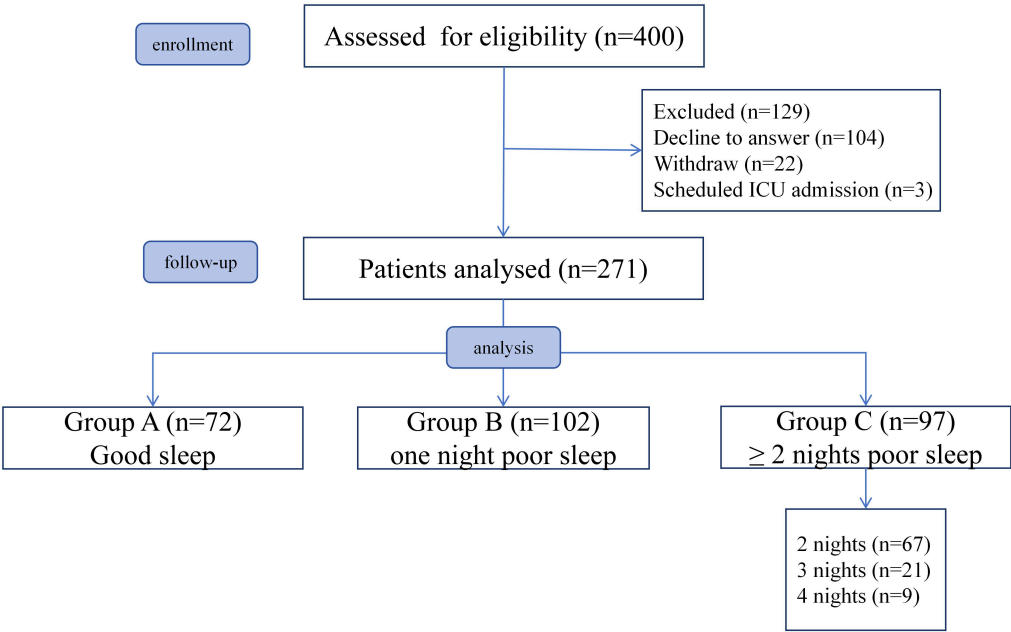


Figure 1

Flow of participants through the study. Of the 400 patients enrolled, 104 declined to answer the questionnaires, 22 withdrew, and 3 were scheduled for ICU admission, leaving 271 patients for analysis. Patients were classified as group A (good sleep quality), group B (one night of poor sleep), or group C (two or more nights of poor sleep).

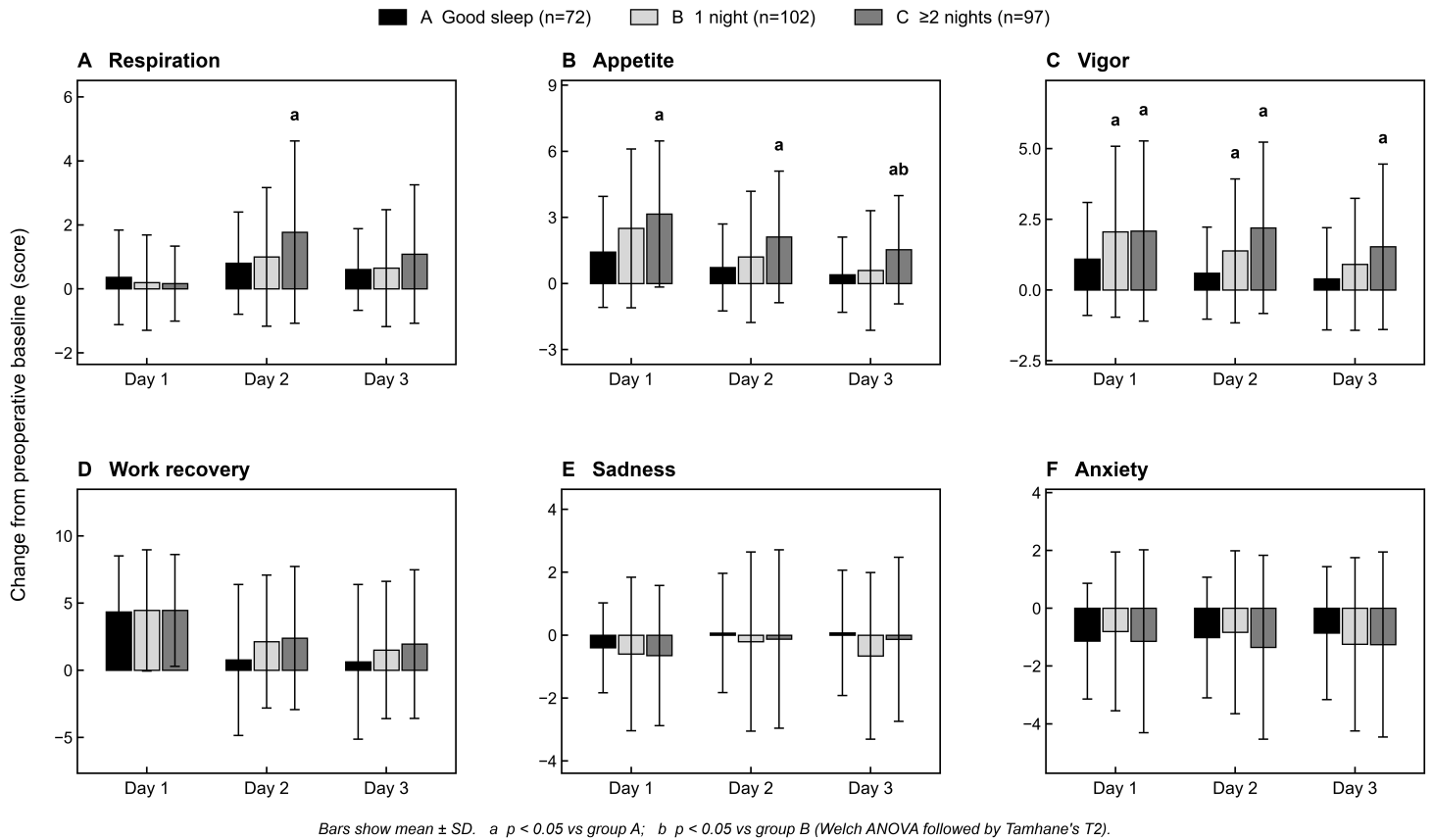


Figure 2

A–F. Changes in individual recovery domains across the three exposure groups. Bars show the mean within-subject change from the preoperative baseline (preoperative score minus postoperative score) on postoperative days 1, 2 and 3; error bars indicate SD. For every item of the scale a score of 10 denotes the best possible state (no symptom or full function), so a positive value indicates a lower postoperative score. Group A = good sleep quality (n = 72); group B = one night of poor sleep (n = 102); group C = two or more nights of poor sleep (n = 97). a $p < 0.05$ versus group A; b $p < 0.05$ versus group B (Welch analysis of variance followed by Tamhane's T2 post hoc test).