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Association Between Surgeon Stress and Major Surgical Complications

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IMPORTANCE Surgeon stress can influence technical and nontechnical skills, but the consequences for patient outcomes remain unknown.

OBJECTIVE To investigate whether surgeon physiological stress, as assessed by sympathovagal balance, is associated with postoperative complications.

DESIGN, SETTING, AND PARTICIPANTS This multicenter prospective cohort study included 14 surgical departments involving 7 specialties within 4 university hospitals in Lyon, France. Exclusion criteria consisted of patient age younger than 18 years, palliative surgery, incomplete operative time-stamping data, procedures with a duration of less than 20 minutes, and invalid surgeon heart rate variability (HRV) data. Data were accrued between November 1, 2020, and December 31, 2021, with 30-day follow-up completed on May 8, 2022. Analyses were performed from January 1 to May 31, 2024.

EXPOSURE Sympathovagal balance of the attending surgeon in the first 5 minutes of surgery.

MAIN OUTCOMES AND MEASURES Major surgical complications, extended intensive care unit stay, and mortality within 30 days, after adjustment via mixed-effects multivariable logistic regression for surgeon age, professional status, the time of incision, the random effect of the surgeon, and a composite risk score incorporating patient comorbidities and surgery characteristics. Sympathovagal balance was quantified by the low frequency to high frequency (LF:HF) ratio derived from HRV data measured by chest monitors worn intraoperatively. The LF:HF ratio was normalized at the surgeon level to the median value observed for each surgeon during the study period to control for baseline differences.

RESULTS A total of 793 surgical procedures performed by 38 attending surgeons were included in the analysis. Median patient age was 62 (IQR, 47-72) years, and 412 (52.0%) were female, with a median of 2 (IQR, 1-4) comorbidities. Median surgeon age was 46 (IQR, 39-52) years, 39 (78.9%) were male, and 22 (57.9%) were professors. Median surgeon heart rate was 88 (IQR, 77-99) beats per minute. Median surgeon LF:HF ratio was 7.16 (IQR, 4.52-10.72) before and 1.00 (IQR, 0.71-1.32) after normalization. Increased surgeon sympathovagal balance during the first 5 minutes of surgery was associated with significantly reduced major surgical complications (adjusted odds ratio [AOR], 0.63; 95% CI, 0.41-0.98; $P = .04$), though not with reduced intensive care unit stay (AOR, 0.34; 95% CI, 0.11-1.01; $P = .05$) or mortality (AOR, 0.18; 95% CI, 0.03-1.03; $P = .05$).

CONCLUSIONS AND RELEVANCE Increased surgeon stress at the beginning of a procedure was associated with improved clinical patient outcomes. The results are illustrative of the complex relationship between physiological stress and performance, identify a novel association between measurable surgeon human factors and patient outcomes, and may highlight opportunities to improve patient care.

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The operating room requires interdisciplinary collaboration to accomplish high-stakes tasks. The resultant complexity begets increased cognitive workload and stress for surgeons and adds to the influence of external personal, professional, and environmental stressors.[1,2] Increased surgeon stress may be associated with worse technical outcomes,[3] decreased efficiency,[4] and diminished capacity to perform nontechnical skills.[4-7] Although performance deficits could plausibly impact patient care, previous studies are limited by the use of simulations[3,5,8-11] or the inclusion of inexperienced operators who may not reflect clinical practice.[8,12-14] Additionally, while these studies examine stress throughout task performance, stress at the start of surgery may be particularly useful because of the relationship between stress preceding athletic or decision-making tasks and both physical and cognitive performance,[15,16] and because it may be more readily modulated than stress caused by intraoperative events. Therefore, prior work has provided important foundational knowledge regarding stress and surgical performance but critically lacks the correlation of surgeon stress with patient outcomes during actionable times in surgery. Inquiry addressing these limitations may transmute surgeon stress from an observation to a useful, modifiable characteristic of the surgical team.

Several qualitative and quantitative metrics can measure surgeon stress. Self-reported assessment tools capture the subjective and experiential elements of stress[17,18] but are obtrusive in the operating room environment, difficult to obtain in real time, and subject to the complex culture surrounding stress among surgical professionals[19] and assume that surgeons accurately perceive their own mental state. Alternatively, physiological measures, including heart rate variability (HRV),[3,20-22] salivary cortisol levels,[3,5,9,23] and pupillary response[11] are objective, quantitative metrics previously correlated with observed and self-reported stress.[24] HRV metrics have been used most commonly.[24] In particular, the low frequency to high frequency (LF:HF) ratio derived from HRV data defines the sympathovagal balance[25] and is associated with self-reported stress and other physiologic measures.[14,22,26-30] In sum, the LF:HF ratio is an objective, validated parameter that enables real-time quantification of stress and might serve as a conduit to systematically examining how variability in a single human factor domain contributes to surgical care.

Therefore, we prospectively measured the LF:HF ratio of attending surgeons across 7 specialties to interrogate the association between surgeon stress, as quantified by sympathovagal balance, and major patient outcomes. Specifically, we focused on surgeon stress in the first 5 minutes of each case, a period potentially amenable to future intervention and less subject to confounding from plausibly adaptive responses to intraoperative events.

Key Points

Question Is surgeon physiological stress, as deduced from the sympathovagal balance measured via heart rate variability analysis, associated with patient outcomes?

Findings In this cohort study including 38 attending surgeons and 793 patients, increased surgeon stress in the first 5 minutes of surgery was associated with a significant reduction in major surgical complications after controlling for patient, surgeon, and surgery characteristics.

Meaning These results suggest that optimizing surgeon stress may offer an avenue to improve surgical performance, with increased stress benefitting patient outcomes for experienced surgeons.

Methods

Study Design and Population

This hypothesis-driven, post hoc analysis of the preintervention phase of a prospective cohort study included 14 surgical departments from 4 university hospitals in Lyon, France, specialized in digestive, orthopedic, gynecologic, urologic, cardiac, thoracic, and endocrine surgery. Of 45 enrolled attending surgeons (each with a minimum of 50 procedures per year), 38 provided written informed consent to use of their data and intraoperative HRV monitoring during five 15-day sessions regularly spaced throughout the study period between November 1, 2020, and December 31, 2021. Three-month follow-up was completed on May 8, 2022. Patients younger than 18 years, those who refused to share their personal data, those undergoing operations for palliative care or organ donation, and those missing operative time-stamping data were excluded. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

In accordance with European General Data Protection Regulation 2016/679, this study used pseudonymized patient data. It was approved by the French Committee of Expertise in Research, Studies, and Evaluations in the Health Domain, the French National Data Protection Authority, and the European Research Council Executive Agency. It was deemed exempt from formal oversight by the Mass General Brigham Institutional Review Board. Written informed consent was waived by French, European, and US ethical committees. Patients had the opportunity to opt out in writing in accordance with the General Data Protection Regulation.

Patient and Surgeon Data Sources

Data were collected from a homogeneous information system across Lyon University hospitals that included the patients' sociodemographic characteristics, the type of surgery performed, and the primary diagnosis linked to the operative indication. Additionally, information was manually collected from the patients' electronic health records to characterize comorbidities, operative time-stamping, intraoperative and postoperative patient outcomes, and anesthetic details. Human resources data determined the age and professional status of attending surgeons.

Attending surgeons wore commercially available sensors (GT3X-BT; ActiGraph) to confirm immobility and chest belts (Polar H10; Polar Electro) to track HRV data for 5 minutes after the incision. The collected data were validated, corrected for noise, and analyzed using HRV software, version 4.0 (Kubios). HRV data are sensitive to physical activity and require 5 minutes of data to assess our primary exposure.[31,32] Therefore, data were excluded for operations lasting less than 20 minutes, without a period of surgeon immobility for 20 minutes or longer, without chest belt data recorded for 5 minutes or longer, or with beat correction of 5% or more during the 5-minute HRV measurement.

Sympathovagal Balance Quantification

HRV is quantified using a variety of metrics. The primary exposure, LF:HF ratio, is a frequency-domain parameter. Rather than directly characterizing the variability in interbeat intervals (time-domain analysis), a fast Fourier transformation is used to assess the relative power in individual frequency domains that together encapsulate changes in HRV.[33] Power in the low-frequency (0.04-0.15 Hz) and high-frequency (0.15-0.40 Hz) domains correlates with sympathetic and parasympathetic tone, respectively.[32,33] A larger LF:HF ratio indicates greater sympathetic tone and physiological stress.[34] Although sympathovagal balance may reflect either physical or cognitive workload, the latter may predominate under our controlled conditions.

Surgical Outcomes

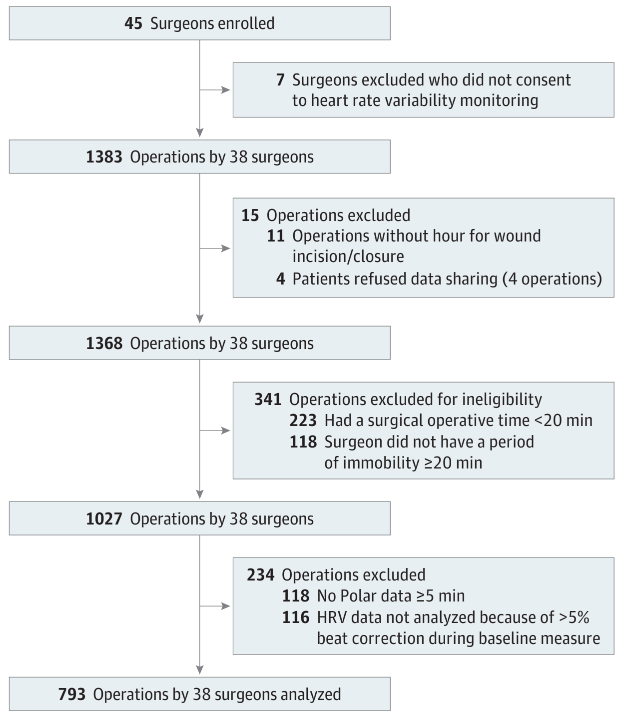
The primary outcome, major surgical complications, incorporated major adverse events during surgery or within the 30-day postoperative period encompassing general (eg, multiorgan failure, shock, or cardiac arrest) and specialty-specific (eg, anastomotic complications, pyeloureteral obstruction, or compartment syndrome) events across general, infectious, hemorrhagic, parietal, cardiopulmonary, neurological, abdominopelvic, orthopedic, cervical, and functional domains. Secondary outcomes included extended intensive care unit (ICU) stay due to organ failure and mortality within 30 days of surgery (eMethods 1 in Supplement 1).

Preoperative risk scores were generated using prediction models developed from an independent dataset of patients undergoing surgery performed by the same cohort of surgeons between January 1, 2022, and October 31, 2022. Potential confounders considered for case-mix adjustment included patient age, sex, comorbidities, American Society of Anesthesiology score, socioeconomic status, and comorbidities and surgical specialty, surgery indication and approach, procedure complexity and scheduling, and the type of anesthesia. We constructed specific models for each specialty and outcome (eMethods 2 in Supplement 1).

Statistical Analysis

Patient characteristics were presented using median (IQR) for continuous variables and frequencies with percentages for categorical variables. To adjust for interindividual variations in baseline sympathovagal balance, the LF:HF ratio for each case was normalized to the median LF:HF ratio across all of each surgeon's cases. Associations between the normalized surgeon LF:HF ratio and patient outcomes were assessed at the surgery level (n = 793). Simple logistic regression assessed the unadjusted associations between the normalized LF:HF ratio and each outcome, with results displayed as odds ratios (ORs) with 95% CIs. Mixed-effects multivariable logistic regression

Figure 1. Flowchart of Included and Excluded Cases



Exclusion criteria were applied to optimize the reliability of heart rate variability (HRV) spectral analysis and the calculation of the low frequency to high frequency ratio. Polar data indicate HRV data obtained from chest belts (Polar H10; Polar Electro) for 5 minutes after the surgical incision. The final cohort included a mean (SD) of 21 (5) operations per surgeon (median, 16.5 [range, 3-66]).

with a maximum likelihood estimation based on the Laplace approximation adjusted for confounding. The model included the logarithm-transformed patient risk score, surgeon age and professional status (to compensate for operative experience and varying professional responsibilities), and the time of day of incision (due to the natural circadian variation in LF:HF ratio) as fixed effects. The surgeon's identity was included as a random effect to account for clustering of patients within each surgeon. Results are displayed as adjusted ORs (AORs) with 95% CIs. The probability of each outcome over a range of LF:HF ratios was estimated from the fixed-effects components of the multivariable model and depicted graphically. Two-sided $P < .05$ defined statistical significance. Data analyses were performed using SAS, version 9.4 (SAS Institute Inc) or RStudio, version 2023.12.1 + 402 (R Program for Statistical Computing). Data were analyzed from January 1 to May 31, 2024.

We performed several sensitivity analyses. First, because normalizing to the surgeon's median observed LF:HF ratio may be sensitive to outliers and nonrepresentative random sampling at small sample sizes, the analysis was repeated including only surgeons with 10 or more cases. Further, we examined the adjusted association between the exposure and each outcome after stratifying into high-risk (cardiac and thoracic), intermediate-risk (digestive and endocrine), and low-risk (orthopedic, urologic, and gynecologic) surgical special-

Table 1. Patient, Surgery, and Surgeon Characteristics

Characteristic	No. (%)[a]
Patient characteristics (n = 793)	
Sex	
Female	412 (52.0)
Male	381 (48.0)
Age, median (IQR), y	62 (47-72)
Body mass index, median (IQR)[b]	26 (23-29)
ASA class	
1	191 (24.1)
2	379 (47.8)
3	205 (25.9)
4	17 (2.1)
5	1 (0.1)
No. of comorbidities, median (IQR)[c]	2 (1-4)
≥1 Comorbidity	666 (84.0)
Procedure characteristics (n = 793)	
Surgical specialty of the operation	
Orthopedic	229 (28.9)
Digestive	148 (18.7)
Gynecologic	127 (16.0)
Urologic	90 (11.3)
Endocrine	89 (11.2)
Cardiac	84 (10.6)
Thoracic	26 (3.3)
Scheduling of the operation	
Elective	715 (90.2)
Semiurgent or urgent	78 (9.8)
Initial surgical approach[d]	
Endoscopic	57 (7.2)
Open	524 (66.3)
Robot-assisted	32 (4.1)
Videoscopic	177 (22.4)
Principal anesthesia technique	
General	656 (82.7)
Locoregional	137 (17.3)
Incision to closure time, median (IQR), min	77 (48-138)
Incision time of day	
Morning	501 (63.2)
Afternoon	268 (33.8)
Overnight	24 (3.0)

(continued)

Table 1. Patient, Surgery, and Surgeon Characteristics (continued)

Characteristic	No. (%)[a]
Surgeon characteristics (n = 38)	
Age at start of study, median (IQR), y	46 (39-52)
Sex	
Female	8 (21.1)
Male	30 (78.9)
Professional status	
Nonprofessor	16 (42.1)
Professor or associate professor	22 (57.9)
Specialty	
Orthopedic	9 (23.7)
Digestive	11 (28.9)
Gynecologic	6 (15.8)
Urologic	5 (13.2)
Endocrine	2 (5.3)
Cardiac	4 (10.5)
Thoracic	1 (2.6)
Heart rate metrics, median (IQR)[d]	
Heart rate, bpm	88 (77-99)
Low frequency absolute power, ms^2	616 (330-1087)
High frequency absolute power, ms^2	91 (43-184)
LF:HF ratio	7.16 (4.52-10.72)
Normalized LF:HF ratio, median (IQR)	1.00 (0.71-1.32)

Abbreviations: ASA, American Society of Anesthesiologists; bpm, beats per minute; HF, high frequency; LF, low frequency.

[a] All continuous variables are described with median (IQR) due to the rejection of the assumption of normality on Shapiro-Wilks test ($P < .05$) and visual assessment of the population histograms.

[b] Calculated as the weight in kilograms divided by the height in meters squared. Data were missing for 3 patients.

[c] Includes critical condition, current pregnancy, obesity (body mass index ≥30), malnourishment, tobacco addiction, alcohol addiction, other addiction, open wound, surgical site infection, sepsis, endocarditis, cancer, neoadjuvant therapy, immune deficiency, coagulopathy, anticoagulant therapy, platelet antiaggregation therapy, blood transfusion, coma, limb paralysis, other neurological disorder, confusion, dementia, depression, cardiovascular disease, neurovascular disease, peripheral arterial disease, cardiac arrhythmia, chronic heart failure, hypertension, diabetes, dyslipidemia, pulmonary artery systolic pressure greater than 60 mm Hg, chronic kidney failure, acute kidney failure, chronic respiratory failure, chronic obstructive pulmonary disease, liver disease, rheumatic pathology, and hypoparathyroidism.

[d] Includes 793 procedures. Data were missing for 3 patients.

ties. In instances of model nonconvergence due to limited event rates within the reduced sample size, covariates were sequentially removed until the model converged.

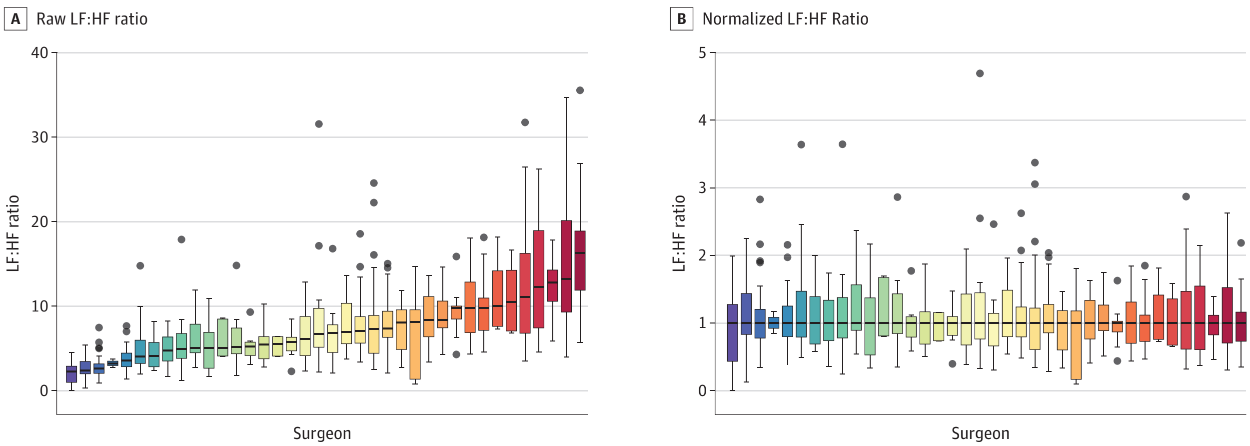
Results

Patient, Procedure, and Surgeon Characteristics

The association between surgeon LF:HF ratio and the outcomes of interest was assessed for a total of 793 patients undergoing surgery performed by 38 surgeons (**Figure 1**). Overall, 412 patients (52.0%) were female and 381 (48.0%) were male; median age was 62 (IQR, 47-72) years; and 666 (84.0%) had at least 1 comorbidity, with a median of 2 (IQR, 1-4) comorbidities (**Table 1**). The number of cases within each specialty included 229 (28.9%) orthopedic, 148 (18.7%) digestive, 127 (16.0%) gynecologic, 90 (11.3%) urologic, 89 (11.2%) endocrine, 84 (10.6%) cardiac, and 26 (3.3%) thoracic. Cases were generally elective (715 [90.2%]), open (524 [66.3%] of 790 with available data), and performed under general anesthesia (656 [82.7%]). Among the surgeons, 8 (21.1%) were female and 30 (78.9%) were male; median age was 46 (IQR, 39-52) years; and 22 (57.9%) were either professors or associate professors. Median surgeon heart rate was 88 (IQR, 77-99) beats per minute (Table 1).

Major surgical complications occurred in 144 patients (18.2%), extended ICU stay in 30 (3.8%), and mortality in 14 (1.8%). Patients who had major surgical complications were

Figure 2. Surgeon Low Frequency to High Frequency (LF:HF) Ratio Normalization



Each box plot represents a single surgeon. Box plots with the same color between the panels represent the same surgeon. A, Box plots of the raw LF:HF ratio values for each surgeon across all cases completed during the study, arranged in order of ascending median value. B, Box plots of the normalized LF:HF ratio values for the same surgeons in the same order after normalizing by dividing each raw LF:HF ratio by the individual surgeon's median value across all of their cases. Boxes indicate the 25th percentile, median, and 75th percentile. Dots represent data greater than 1.5 times the IQR from the median. Whiskers show the minimum and maximum ranges.

Table 2. Mixed-Effects Multivariable Logistic Regression Models Associating Surgeon Normalized LF:HF Ratio and Operative Outcomes[a]

	Major surgical complication		Extended ICU stay		Mortality	
Covariate	AOR (95% CI)	P value	AOR (95% CI)	P value	AOR (95% CI)	P value
Normalized LF:HF ratio	0.63 (0.41-0.98)	.04	0.34 (0.11-1.01)	.05	0.18 (0.03-1.03)	.05
Surgeon age	1.01 (0.98-1.04)	.53	1.01 (0.95-1.07)	.80	1.09 (1.01-1.19)	.04
Surgeon professional status						
Nonprofessor	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Professor or assistant professor	0.72 (0.42-1.24)	.23	0.61 (0.23-1.60)	.31	0.29 (0.07-1.19)	.09
Incision time of day						
Morning	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Afternoon	1.30 (0.83-2.03)	.25	2.21 (0.91-5.38)	.08	1.73 (0.44-6.83)	.44
Overnight	0.58 (0.18-1.85)	.36	3.12 (0.66-14.9)	.15	1.25 (0.17-9.24)	.83
log(Risk score)	2.88 (2.28-3.63)	<.001	3.00 (2.18-4.14)	<.001	2.29 (1.62-3.23)	<.001

Abbreviations: AOR, adjusted odds ratio; ICU, intensive care unit; LF:HF, low frequency to high frequency; NA, not applicable.

[a] Mixed-effects logistic regression model adjusted for surgeon professional status, surgeon age, time of day of the incision, the logarithm of the specific patient risk score developed for each outcome measure and the random effect of the primary surgeon. Six patients were excluded from the multivariable model due to missing data precluding calculation of the risk score (n = 787).

more frequently within high-risk specialties, had more comorbidities, and more frequently had open surgery (eTable 1 in Supplement 1). The measured median LF:HF ratio of the primary surgeon was 7.16 (IQR, 4.52-10.72) before normalization. Substantial intrasurgeon and intersurgeon variability in the LF:HF ratio was observed (**Figure 2**A). After normalization, the median LF:HF ratio was 1.00 (IQR, 0.71-1.32), and the range was 0.001 to 4.69 (Figure 2B).

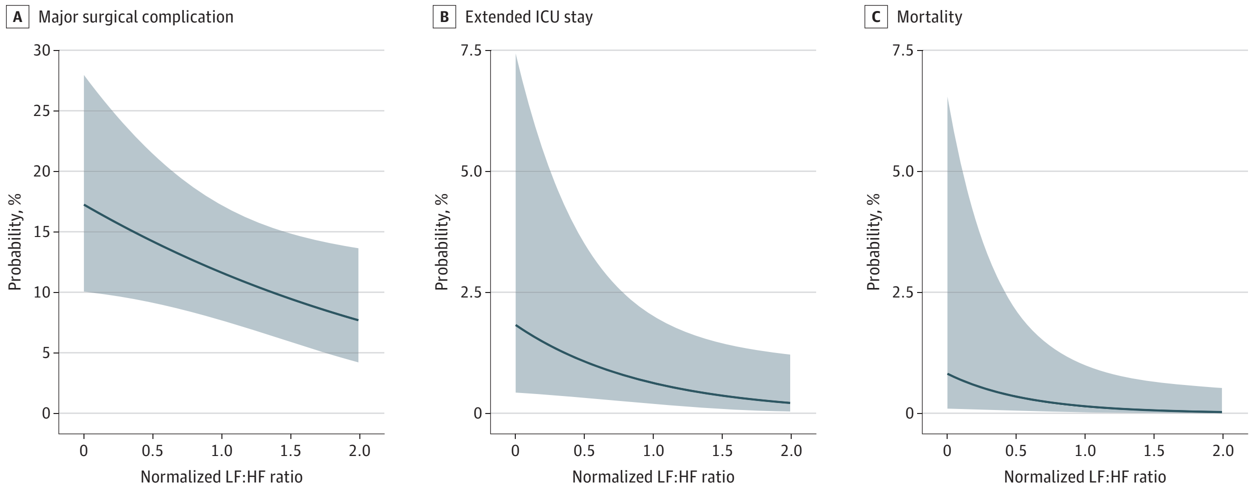
Association Between Surgeon Sympathovagal Balance and Major Surgical Complications

Increased surgeon sympathovagal balance during the first 5 minutes of surgery as measured by LF:HF ratio was associated with reduced major surgical complications (OR, 0.65; 95% CI, 0.43-0.95; *P* = .03). The association was similar after adjusting for patient and surgeon characteristics (AOR, 0.63; 95% CI, 0.41-0.98; *P* = .04) (**Table 2** and **Figure 3**). The association remained after restricting the analysis to surgeons who performed at least 10 procedures (AOR, 0.59; 95% CI, 0.36-0.96; *P* = .03) (eTable 2 in Supplement 1) but not when it was restricted to high-risk surgical specialties (AOR, 0.42; 95% CI, 0.15-1.13; *P* = .09) (eTable 3 in Supplement 1).

Association Between Surgeon Sympathovagal Balance and Secondary Outcomes

Increased surgeon sympathovagal balance during the first 5 minutes of surgery was associated with significantly reduced extended ICU stay (OR, 0.35; 95% CI, 0.13-0.84; *P* = .03) and mortality (OR, 0.21; 95% CI, 0.04-0.80; *P* = .04). Both associations were directionally unchanged but were absent after adjustment (AORs, 0.34 [95% CI, 0.11-1.01; *P* = .05] and 0.18 [95% CI, 0.03-1.03; *P* = .05], respectively) (Table 2 and Figure 3).

Figure 3. Adjusted Association Between Normalized Low Frequency to High Frequency (LF:HF) Ratio and Surgical Outcomes



Effect plots demonstrating the association between surgeon normalized LF:HF ratio and the probability of the indicated outcome after adjusting for surgeon age, surgeon professional status, time of day of the initial incision, and the logarithm of the associated patient risk score. Continuous covariates that are not the primary exposure are centered at the cohort mean, while categorical ones are set to the reference value. The curve does not incorporate the random effect of the performing surgeon. The chosen range represents approximately 2 SDs (1 SD = 0.51) above and below the median (1.00) of the normalized LF:HF ratio. Shaded areas represent the 95% CI. ICU indicates intensive care unit.

Results were similar after restricting the analysis to surgeons who conducted at least 10 cases (AORs, 0.34 [95% CI, 0.10-1.12; *P* = .08] and 0.14 [95% CI, 0.01-1.43; *P* = .10], respectively) (eTable 2 in Supplement 1). After stratifying into surgical specialty risk groups, increased LF:HF ratio was associated with a significantly reduced extended ICU stay (AOR, 0.17; 95% CI, 0.03-0.87; *P* = .03) in the high-risk group (eTable 3 in Supplement 1); mortality was not explored in this sensitivity analysis due to model nonconvergence related to the reduced sample size and low frequency of mortality.

Discussion

This cohort study demonstrates a significant, inverse association between attending surgeon stress at the beginning of an operation, as indicated by sympathovagal balance, and the odds of major surgical complications after adjustment for patient and surgeon characteristics. These results remained robust in sensitivity analyses conducted across various outcomes and patient subpopulations. Overall, while a direct causal relationship cannot be inferred based on our study design, we provide empirical evidence that intraoperative stress among experienced surgeons is associated with patient outcomes and may warrant attention from future efforts geared toward improving surgical care.

Successful surgery requires a combination of technical skills, which are essential for completing the surgical procedure itself, and nontechnical skills, particularly those related to teamwork in the operating room. Both skill sets can influence postoperative outcomes.[35-37] In previous studies, stress has deleteriously affected both technical and nontechnical skills. For example, poor stress coping strategies were associated with increased task completion time and compromised technical outcomes in simulations,[3,8] while distractions and time pressure were associated with impaired dexterity.[38] Increased stress as measured by HRV was associated with increased potentially harmful events,[39] and surgeons reported that excessive stress negatively impacted judgment and communication.[6,19] Therefore, our present results may be counterintuitive in suggesting that increased surgeon stress is associated with better surgical outcomes.

However, stress is a complex phenomenon whose understanding has evolved from that of a nonspecific response to noxious environmental stimuli[40] to a coalescence of chronic and acute and positive and negative influences[41] with differential responses to and effects on each individual.[42] Further, the association between stress or arousal and task performance may be nonlinear, with moderate degrees of stress associated with optimal performance,[41,43] as observed in multiple fields ranging from athletics[44] to the workplace.[45] This phenomenon echoes the concept of optimal sympathetic and parasympathetic tone facilitating a "flow state."[46] Within surgery specifically, 1 study found decreased technical error rates among expert practitioners with increased cognitive activity and speculated that experts err secondary to understimulation.[11] This is consistent with surgeons describing some degree of stress being conducive to performance[6,19] and simulation evidence demonstrating a benefit of increased cognitive workload during training for subsequent performance.[47] The effect of stress may also be modulated by surgeon experience, with novices more likely to have performance decrements from stress compared with experts,[11] potentially mediated by enhanced coping mechanisms in experienced surgeons.[3,5,6,8] Regardless of experience, excessive stress or cognitive overload is recognized as a contributor to surgical errors.[48,49]

Taken together, although excessive stress or cognitive workload may harm surgical performance, modest amounts of stress may stimulate better performance in individuals with requisite levels of experience and coping abilities. Of note, our study included exclusively attending surgeons performing predominantly elective surgical procedures. It is possible that our experienced surgeon population was well equipped to cope with increased stress and that we lacked a sufficient volume of high-complexity, high-stress cases exceeding their compensatory capacity to detect a harmful effect of stress. Within the confines of our study population, our results are consistent with suggestions that a limited increase in stress may optimize performance.

While our findings describe only associations in a nonrandomized setting, the validity of our results is bolstered by our study design. Data were prospectively collected from a unique, multispecialty cohort over an extended period of time using an objective stress measure, thus limiting bias and circumventing the drawbacks of subjective surveys. Furthermore, while most prior work examining surgeon stress has studied trainees or used simulated environments, our study emulates clinical practice by including attending surgeons and actual patients. Importantly, we also uniquely focus on the first 5 minutes of surgery. Surgeon stress and related physiologic changes expectedly vary throughout the course of a given procedure[26,50,51] and are influenced by events such as bleeding, distractions, equipment failures, and other unanticipated occurrences,[4,30,52] rendering it difficult to establish the direction of causality—did bleeding engender surgeon stress, or did increased stress lead to errors and bleeding? The first 5 minutes of surgery are less subject to these confounding elements and more likely reflect surgeon physiology related to mental preparation, the operating room environment, or lifestyle influences. To our knowledge, previous studies have not focused on this period, which may partially explain our novel findings.

In the context of current surgical trends, human factors concepts recognize that environmental and systems influences may modify surgeon abilities while also impacting quality of life and patient safety.[53] However, without objective approaches to quantify human factors elements and assess the efficacy of related interventions, the benefits of such paradigms remain difficult to realize. Our results suggest that surgeon stress as sympathovagal balance provides an objective method of characterizing the variability in 1 surgeon's human factors characteristic and its downstream consequences for patients. Some research suggests lifestyle (eg, sleep and exercise), organizational, environmental (eg, operating team members and logistics), and sociocultural influences can contribute to perceived surgeon stress.[54,55] In addition, HRV can be concertedly modulated via biofeedback techniques, with demonstrated benefits to emotional health and sport performance.[56,57] While such options offer promise in affecting patient care, our results will need to replicated, ideally in a randomized clinical trial, and extended to identify the optimal level of sympathovagal balance for surgical performance before they are clinically feasible.

Whether the change in the HRV per se or its causative influences are responsible for the observed improvement in surgical outcomes remains an open question, but both present modifiable avenues to alter surgeon stress and potentially influence patient care. Other disciplines such as aviation have established cultural values that identify practitioner stress as a contributor to errors, emphasize its role in root cause analyses, and actively consider ways to mitigate its adverse sequela on both crew well-being and team performance.[58] Efforts to influence surgeon's behavior and their LF:HF ratio or related measures should take into account that chronic changes in HRV have been associated with adverse neurological and cardiovascular health outcomes,[59,60] though we believe acute changes are unlikely to warrant concern. Ultimately, while our results suggest increasing surgeon stress may beneficially impact surgical outcomes, balancing patient considerations with possible ramifications for surgeons will need to be carefully considered.

Limitations

This study has some limitations. First, although LF:HF ratio is the most commonly used objective measure of intraoperative stress, its reliability has been questioned due to nonlinear interactions between the sympathetic and parasympathetic nervous systems, respiratory variability, and ambiguity relative to more sophisticated analytic approaches.[61-63] Second, although the LF:HF ratio has been well correlated with other measures of stress previously, we did not correlate our findings with other concurrent measures of psychological stress or have the requisite observational data to distinguish between different causes, either subjectively positive or negative, of increased stress. Additionally, the heterogeneous surgical population renders case-mix adjustment complex, and we did not control for the surgeon's intake of caffeine, alcohol, tobacco, or pertinent medications that can impact HRV. Residual confounding may, therefore, impact our results. Last, the high proportion of male surgeons, restricted geographic area, and contexts of care included limit generalizability.

Conclusions

In this cohort study, increased stress in attending surgeons, as measured by sympathovagal balance at the start of surgery, was associated with a significant reduction in major surgical complications. The results suggest an association between human factors elements and patient outcomes while highlighting the complex association between physiological stress and surgeon performance. The quantitative assessment of surgeon stress may thereby enable future efforts toward optimization pursuant to enhanced patient outcomes.

ARTICLE INFORMATION

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