How Does Surgeons' Autonomic Physiology Vary Intraoperatively?

A Real-time Study of Cardiac Reactivity

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Objective: To measure the physiological responses of surgical team members under varying levels of intraoperative risk.

Background: Measurement of intraoperative physiological responses provides insight into how operation complexity, phase of surgery, and surgeon seniority impact stress.

Methods: Autonomic nervous system responses (interbeat intervals, IBIs) were measured continuously during different surgical operations of various complexity. The study investigated whether professional role (eg attending surgeon), operative risk (high vs. low), and type of primary operator (attending surgeon vs. resident) impacted IBI reactivity. Physiological synchrony captured the degree of correspondence between individuals' physiological responses at any given time point.

Results: A total of 10,005 observations of IBI reactivity were recorded in 26 participants during 16 high-risk (renal transplant and laparoscopic donor nephrectomy) and low-risk (arteriovenous fistula formation) operations. Attending surgeons showed greater IBI reactivity (faster heart rate) than residents and nurses during high-risk operations and while actively operating ($Ps < 0.001$). Residents showed lower reactivity during high-risk (relative to low-risk) operations ($P < 0.001$) and similar reactivity regardless of whether they or the attending surgeon was operating ($P = 0.10$). Nurses responded similarly during low-risk and high-risk operations ($P = 0.102$) but were more reactive when the resident was operating compared to when the attending surgeon was the primary operator ($P < 0.001$). In high-risk operations, attending surgeons had negative physiological covariation with residents and nurses ($P < 0.001$). In low-risk operations, only attending surgeons and nurses were synchronized ($P < 0.001$).

Conclusion: Attending surgeons' physiological responses were well-calibrated to operative demands. Residents' and nurses' responses were not, callibrated to the same extent. This suggests that risk sensitivity is an adaptive response to stress that surgeons acquire.

Keywords: heart rate, intraoperative stress, physiological synchrony, surgeons, team coordination

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Surgeons and operating room teams are subjected to multiple stressors, including environmental, organizational, and interpersonal risk factors.[1–4] These stressors can adversely affect patient safety, leading to avoidable errors in technical performance, decision-making, and teamwork.[5–8] Workplace stress also negatively impacts the health of operating room staff, resulting in burnout, as well as metabolic and cardiovascular morbidity.[9–11]

To date, there has been limited work examining stress in the operating room using continuous physiological metrics. Previous research has focused on self-assessments of stress, which are prone to reporting bias,[2,12] and have been limited to stress measurement in simulated surgical environments, which do not replicate the demands of the operating room.[6,13–16] The advent of wearable technology has facilitated the continuous and unobtrusive capture of cardiovascular data from operating room personnel in real time, providing a method of capturing stress via changes in autonomic arousal.[17] In this study, we use metrics of sympathetic nervous system (SNS) activation[18] to capture interbeat intervals (IBIs), defined as milliseconds between heartbeats. IBIs are a time-domain measurement that capture fluctuations in cardiac activity beat by beat and track changes in activation.[19–21] Lower IBI values represent shorter time intervals between successive heartbeats, most likely indicating greater SNS responses.

IBIs are associated with responses to stressors in high-stakes interaction contexts.[22,23] Operations are characterized by a flux and flow of demand, marked by acutely stressful moments that require immediate attention and team coordination.[2,24] The use of cardiovascular reactivity allows the capture of continuous stress responses over the entire course of operations. This provides an advantage over intermittent or disruptive approaches, such as salivary cortisol measurement,[14] while circumventing sampling limitations related to surgical sterility. Dynamic changes in physiological responses to situational demands may be especially important in the operating room, where optimal performance relies on technical precision and team coordination.[25,26]

AIMS

The objective of this study is to examine surgeons' and operating room personnel's responses to intraoperative stress by measuring changes in physiological arousal at different phases of surgery. The study also tested whether surgical teams' stress responses are synchronized during operations. The study aims to answer 3 questions: (1) Do stress responses vary between low-and high-risk operations? (2) Do team members respond differently when the attending surgeon (versus resident) is operating? (3) Are team members' physiologic responses synchronized?

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METHODS

Study Design

The study measured surgical team members' continuous physiological responses (IBIs) during operations for renal replacement therapy (e.g. renal transplant or formation of arteriovenous fistulas). Autonomic nervous system responses were collected from attending and resident surgeons, anesthetists, and nurses. The risk level was operationalized as the risk of major intraoperative bleeding and the technical complexity of the case.[27] To study the effect of risk on stress responses, operations were dichotomized into either low-risk/low-technical complexity (arteriovenous fistula formation) or high-risk/high-technical complexity (renal transplant or hand-assisted laparoscopic donor nephrectomy) categories. Case screening for inclusion was not based on case complexity, but rather on scheduling order. None of the cases included were considered training cases but were routinely planned operations. The study also examined whether team members responded differently when the attending surgeon was operating compared with the resident. Lastly, the study examined the degree of within-time point covariation between team members' physiology. This tested whether team members' stress responses were synchronized, which can be an indicator of shared affective states among the operating room personnel.[28]

Participant Recruitment

Professional networks were used to recruit operating room staff performing real-world index cases in a tertiary academic transplant center in London, UK. The selection was based on predefined eligibility criteria. Individuals with a body mass index > 33, preexisting cardiac disease, diabetes, or those using beta-blockers were ineligible to participate (Appendix A, section 1.1, Supplemental Digital Content 1, http://links.lww.com/SLA/E797).

Physiological Measures

Autonomic physiology was recorded by fitting participants with chest straps attached to Polar H7 heart rate monitors (Polar Electro Oy; Appendix A, sections 1.2–1.4, Supplemental Digital Content 1, http://links.lww.com/SLA/E797). Healthy physiological responses involve adapting to changes in the environment and preparing the body to respond to physical and cognitive demands.[29] Shifts in physiology that correspond with situational demands can be beneficial for performance and cognitive control,[30,31] such as elevated SNS reactivity during high-risk procedures and decreased SNS reactivity when demand is low. Physiological reactivity was measured using IBIs, a time-domain measure of heart rate (also known as heart period) which are inversely correlated with heart rate measured in beats per minute. IBIs are linearly related to cardiac activation, whereas heart rate in beats per minute is considered nonlinear and can exaggerate the interaction between sympathetic and parasympathetic systems. Thus, IBIs are considered psychometrically superior to heart rate measurements in time-series data.[32] Decreased IBIs signify shorter time intervals between heartbeats and increased physiological arousal. Physiological reactivity was used to assess changes in arousal relative to that individual's baseline. Surgery is inherently stressful, making it challenging to record resting physiology as a baseline measurement. In line with prior work, the baseline value was instead determined as the minute with the lowest heart rate, considering the IBI within that minute as the baseline.[33] IBI reactivity was computed as the difference in IBIs moment-to-moment compared with the baseline IBI, such that greater values represented stronger physiological arousal relative to their baseline responses (Appendix A, Supplemental Digital Content 1, http://links.lww.com/SLA/E797, Fig. 1).

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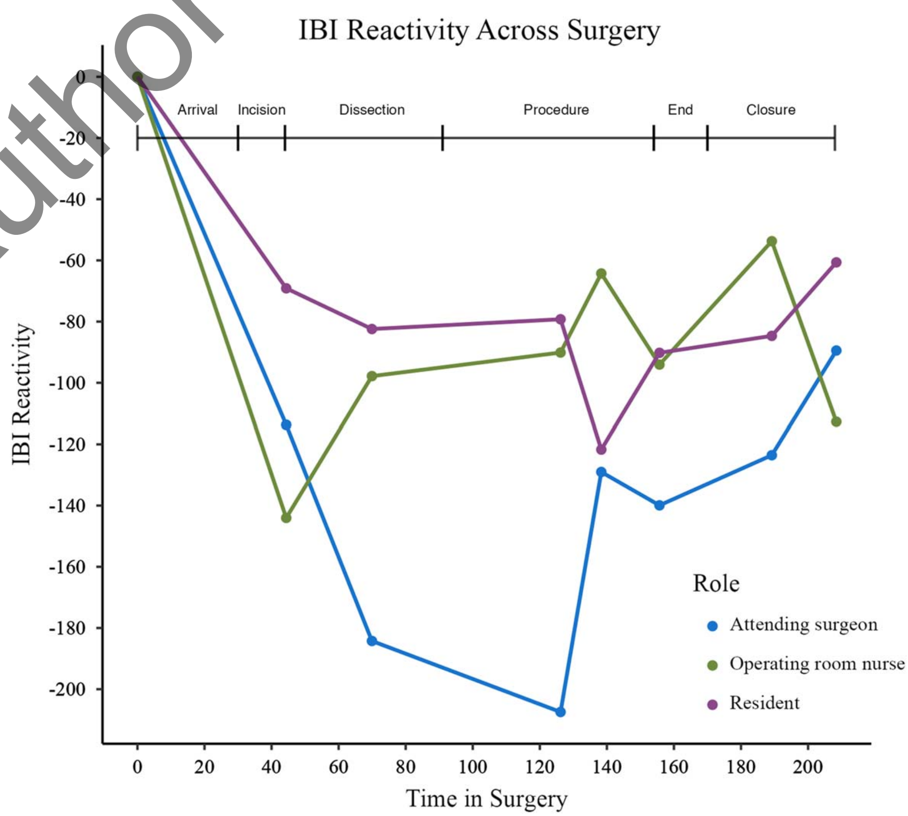

FIGURE 1. IBI reactivity across all operations with the corresponding event timeline. Lower values indicate greater reactivity.

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All index operations were observed by 2 embedded researchers who recorded routine and unexpected intraoperative events (see Appendix B, section 2.6 for unexpected events, Supplemental Digital Content 1, http://links.lww.com/SLA/E797). The study examined whether changes in IBIs over the course of the operation varied according to operation type (high vs low risk), professional role, phase of surgery (event) and whether that phase of the operation was led by the attending surgeon or resident (primary operator).

Physiological Covariation

Covariation is the degree of interdependence between operating room personnels' physiology and refers to the correlation between 2 individuals' physiological responses at the same time point.[28] Covariation can capture whether team members share a similar affective state, which broadly refers to shared emotions, stress, and motivations. The presence of covariation suggests that team members are similarly assessing and responding to the demands of the operation. If there is a tradeoff in effort, in which one member shows a stronger physiological response when operating while the nonoperating member exhibits a weaker physiological response, then these covarying responses would be inversely related, resulting in *negative covariation*. Covariation offers insight into team dynamics and reveals whether team members' responses match or diverge during the operation (Appendix A, section 1.3, Supplemental Digital Content 1, http://links.lww.com/SLA/E797).

Operation Timeline

Physiological data were divided into one-minute segments and analyzed by 3 intraoperative markers. First, generic events were identified for all operations (eg, knife to skin, start of skin closure). Second, key operation-specific events were defined (eg, start of anastomosis time for renal transplants). Equivalent points in different operations were established to provide comparable analysis and alignment of timelines (eg, start of skin closure or vessel dissection; see Appendix A, section 1.6 for timeline, Supplemental Digital Content 1, http://links.lww.com/SLA/E797). Unexpected events were logged on a case-by-case basis (eg, unexpected interruption of the surgeon or an equipment failure; Appendix B, section 2.6, Supplemental Digital Content 1, http://links.lww.com/SLA/E797). Third, the study recorded which team member was the primary operating surgeon (attending surgeon or resident) during each event. In all operations, the attending surgeon and resident took turns operating.

Analytic Strategy

Data were analyzed using generalized estimating equations, an analysis strategy for repeated measures multilevel data (Appendix A, section 1.7, Supplemental Digital Content 1, http://links.lww.com/SLA/E797).[34] To measure covariation between team members, we modeled the physiological relationships within the team by examining all 3 dyadic relationships: the degree of physiological similarity within time point between the attending surgeon and resident (dyad type 1), the attending surgeon and operating room nurse (dyad type 2), and the resident and operating room nurse (dyad type 3; Fig. 2). Covariation was estimated as the degree to which individuals' physiological responses were correlated within a single time point. A positive correlation indicates that the dyad member's responses were synchronized, whereas a negative correlation indicates that as one individual's IBI increases, the other person's IBI decreases. We then included moderators of covariation: dyad types (1, 2, and 3) and risk of the operation (high vs low risk), and the primary operator (attending surgeon vs resident), which we were able to examine given the repeated measures nature of the data.

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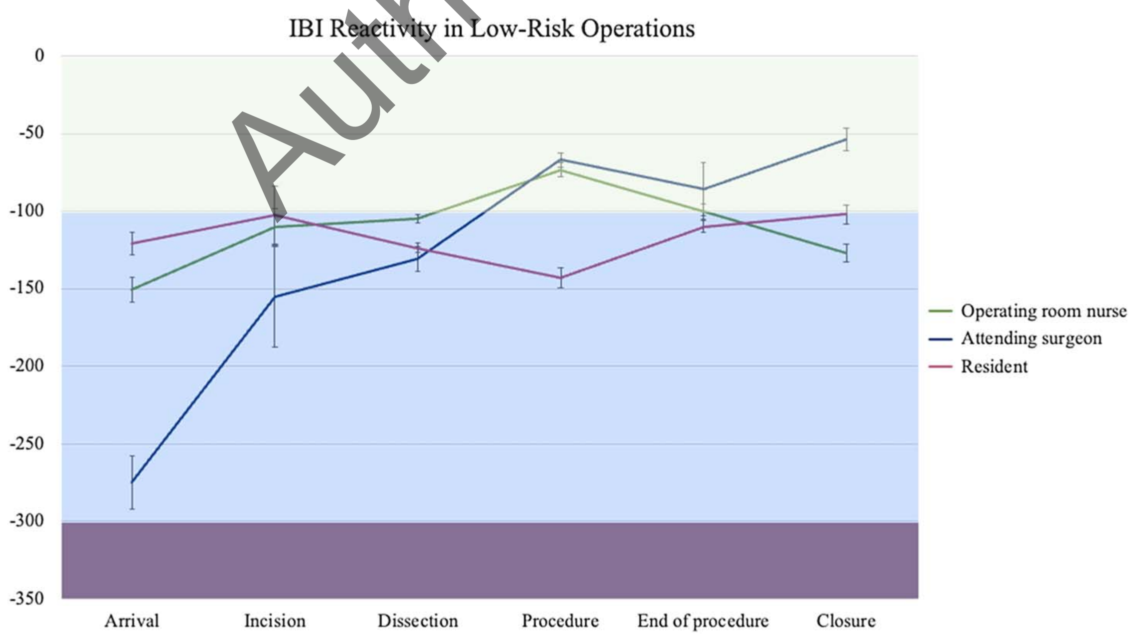

FIGURE 2. IBI reactivity by event in low-risk operations. Lower values indicate greater reactivity (change in IBI relative to baseline). Low, moderate, and high arousal are white (top), light gray (middle), darker gray (bottom) bands.[35,36] Low arousal ranges from 0 to −100 (~0–10 bpm increase). Moderate arousal ranges from −100 to −300 (~11–25 bpm increase). High arousal is −300 or greater (~ > 25 bpm).

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RESULTS

Data Description

The study recruited 36 operating room staff, consisting of 16 surgical teams. Participants were aged 18 to 70 years old. Anesthetists and 4 operating room nurses were excluded from the final analysis due to excessive data loss caused by frequent excursion outside the data capture perimeter. The final sample (N = 26) included 9 attending surgeons ($M_{age}=46$, $SD_{age}=5.71$, $N_{female}=2$), 8 surgical residents ($M_{age}=38$, $SD_{age}=4.43$, $N_{female}=4$), and 9 operating room nurses ($M_{age}=35$, $SD_{age}=8.68$, $N_{female}=8$). Participants varied in experience within their respective roles with attending surgeons reporting an average experience of 5.38 (SD = 5.91) years, residents 5.44 (SD = 5.57) years, and nurses 4.44 (SD = 5.22) years (Appendix B, sections 2.2–2.3, Supplemental Digital Content 1, http://links.lww.com/SLA/E797). A total of 10,005 IBIs were collected continuously during surgery.

Low-risk operations (N = 5) consisted of the formation of arteriovenous fistulae for dialysis and ranged in duration from 61 to 228 minutes ($M=117$, SD = 60.7). High-risk cases included hand-assisted laparoscopic living donor nephrectomy (N = 8) and renal transplants (N = 3). High-risk operations were typically more time-intensive relative to low-risk operations, with hand-assisted laparoscopic living donor nephrectomy ranging from 195 to 279 minutes ($M=247$, SD = 25.6) and renal transplants lasting between 234 to 307 minutes ($M=259$, SD = 35.5).

Reactivity in High-risk Versus Low-risk Operations

We tested whether physiological responses varied as a function of role (ie, team member's role), event (ie, phase within the operation), and risk of the operation (low or high risk) while adjusting for the effects of sex, age, and body mass index. We set statistical significance to P value <0.05 as is standard for field-based psychophysiology studies (Table 1):

- High-risk operations resulted in higher "stress" (greater reactivity/shorter IBIs) than low-risk operations.
- Attending surgeons had greater reactivity than residents and nurses (Fig. 1).
- The more complicated phases of surgery (events) resulted in greater reactivity than the easier parts of the operation.

There was a significant 3-way role×risk×event interaction (Wald $\chi^2_{10}=309.259$, $P<0.001$) (Figs. 2, 3), indicating that team members responded differently depending on the risk level of the operation and difficulty of the phase of the operation (event). Attending surgeons showed greater reactivity in high-risk operations relative to low-risk ones ($b=0.53$, SE = 0.10, Wald $\chi^2_1=27.86$, $P<0.001$). Conversely, residents were less reactive in high-risk operations compared with low-risk ones ($b=-0.61$, SE = 0.05, Wald $\chi^2_1=128.02$, $P<0.001$). Operating room nurses were similarly reactive regardless of operative risk ($b=-0.07$, SE = 0.05, Wald $\chi^2_1=2.68$, $P=0.102$) (Appendix B, sections 2.4–2.5, Supplemental Digital Content 1, http://links.lww.com/SLA/E797).

Primary Operator Analyses

The study also examined whether IBI reactivity varied as a function of who the primary operator was (resident or attending surgeon). A main effect of primary operator was found (Wald $\chi^2_1=34.755$, $P<0.001$) along with the following 2-way interactions: risk × primary operator ($\chi^2_1=51.292$, $P<0.001$) and role×primary operator ($\chi^2_2=320.397$, $P<0.001$) (Figs. 4, 5).

- Residents exhibit similar levels of reactivity regardless of who is operating (themselves or the attending surgeon) ($P=0.10$).
- Attending surgeons exhibit stronger reactivity when operating compared with when the resident is operating ($P<0.001$).
- Operating room nurses, in contrast, are more reactive when the resident is operating relative to when the attending surgeon is operating ($P<0.001$).

The 3-way role × risk × primary operator interaction was not significant ($\chi^2_1=1.909$, $P=0.167$) indicating that the effect of the role and primary operator on IBI reactivity was consistent across high-risk and low-risk operations. These findings provide further evidence that differences in reactivity between team members were not simply due to physical demand or certain team members engaging in more complex aspects of the operation. If this were the case, both attending surgeons and residents

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TABLE 1. Comparisons of IBI Reactivity by Risk, Primary Operator, Role, and Comparisons of Covariation Between Team Members

			Attending surgeon	Resident	Operating room nurse
Risk of operation	Low risk vs high risk		0.53*** (0.10)	−0.61*** (0.05)	−0.07*** (0.04)
Primary operator	Attending surgeon vs resident operating		−0.97*** (0.05)	0.14 (0.08)	0.47*** (0.05)
			Resident—attending surgeon	Nurse—resident	Attending surgeon—nurse
Covariation	Low risk		0.02 (0.03)	−0.01 (0.06)	0.23*** (0.04)
	High risk		−0.42*** (0.02)	−0.18*** (0.03)	−0.34*** (0.04)
	Low vs high risk		−0.20*** (0.02)	−0.10** (0.04)	−0.51 (0.03)
	Low risk	Resident—attending surgeon		−0.03 (0.07)	0.22*** (0.05)
		Operating room nurse—resident	0.03 (0.07)		0.25*** (0.07)
		Attending surgeon—nurse	−0.22*** (0.05)	−0.25*** (0.07)	
	High risk	Resident—attending surgeon		0.24*** (0.04)	0.09† (0.05)
		Operating room nurse—resident	−0.24*** (0.04)		−0.16** (0.06)
		Attending surgeon—nurse	0.09† (0.05)	0.16** (0.06)	

Standardized coefficients are displayed, and SEs are given in parentheses.

For covariation, values represent the correlation between each dyad member's physiological responses. Positive values indicate positive covariation (synchronized responses) and negative values indicate negative covariation (mismatched responses).

*$P<0.05$.

**$P<0.01$.

***$P<0.001$.

†$P<0.10$.

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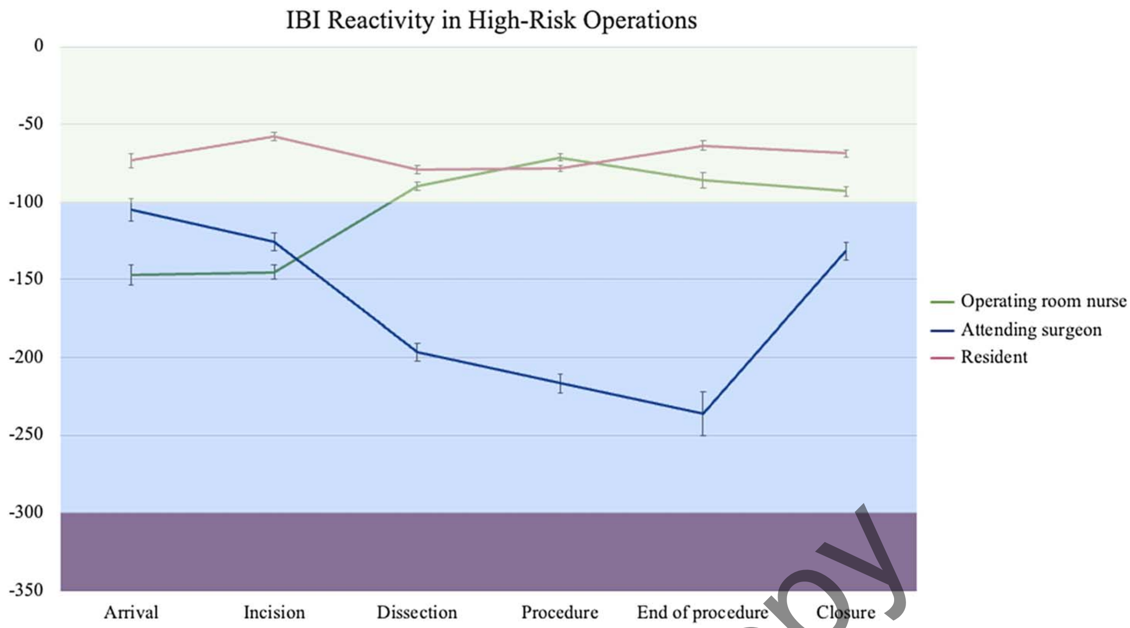

FIGURE 3. IBI reactivity by event in high-risk operations. Lower values indicate greater reactivity (change in IBI relative to baseline). Low, moderate, and high arousal are white (top), light gray (middle), darker gray (bottom).[35,36] Low arousal ranges from 0 to –100 (~0–10 bpm increase). Moderate arousal ranges from –100 to –300 (~11–25 bpm increase). High arousal is –300 or greater (~ > 25 bpm).

would show stronger reactivity when acting as primary operator, and there would be no effect on the nurses. Instead, attending surgeons show more selective physiological responses than residents and operating room nurses. They also exhibit stronger reactivity when they are the primary operator across both high-risk and low-risk operations.

Physiological Covariation

To examine covariation, we tested whether IBI reactivity varied as a function of partner IBI reactivity, the composition of the dyad, and the risk level of the operation. All main effects and 2-way interactions were significant, as described below (Table 1). In addition, there was a significant 3-way interaction (Wald

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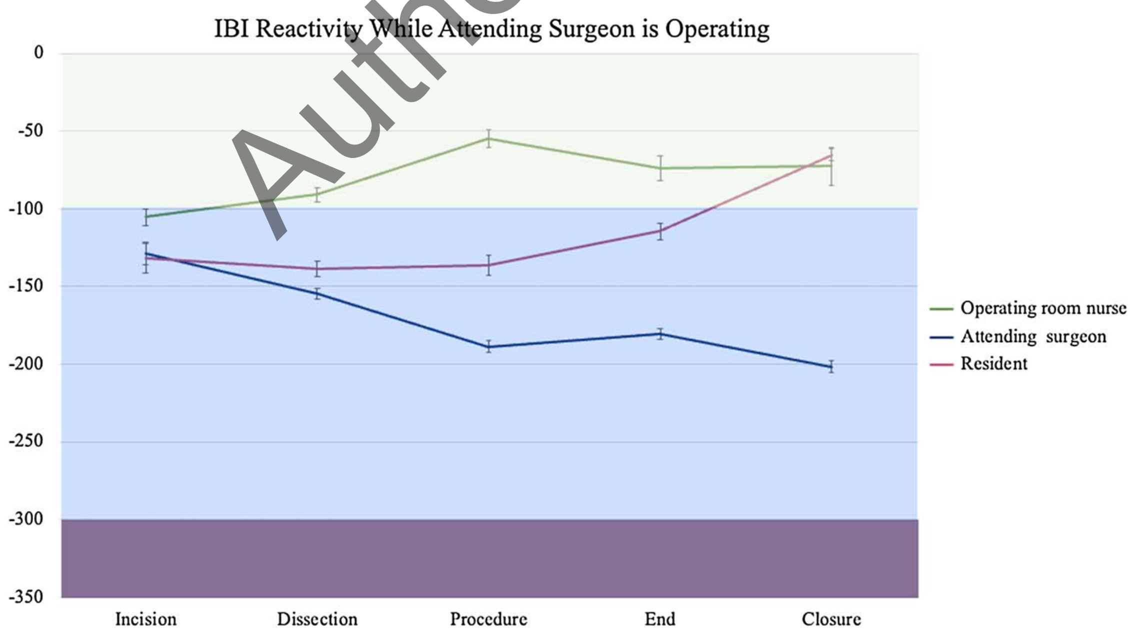

FIGURE 4. IBI reactivity during each phase of the operation when the attending surgeon is the primary operator. Lower values indicate greater reactivity (change in IBI relative to baseline). Low, moderate, and high arousal are represented white (top), light gray (middle), darker gray (bottom).[35,36] Low arousal ranges from 0 to –100 (~0–10 bpm increase). Moderate arousal ranges from –100 to –300 (~11–25 bpm increase). High arousal is –300 or greater (~ > 25 bpm).

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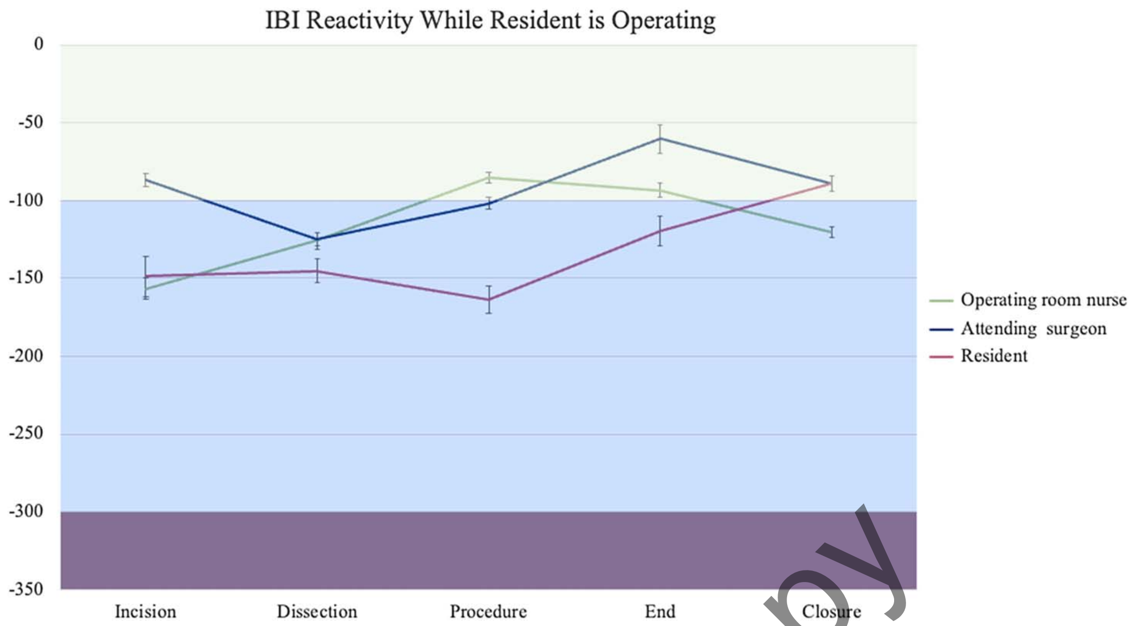

FIGURE 5. IBI reactivity during each phase of the operation when the resident is the primary operator. Lower values indicate greater reactivity (change in IBI relative to baseline). Low, moderate, and high arousal are represented white (top), light gray (middle), darker gray (bottom).[37,38] Low arousal ranges from 0 to –100 (~0–10 bpm increase). Moderate arousal ranges from –100 to –300 (~11–25 bpm increase). High arousal is –300 or greater (~ > 25 bpm).

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$\chi^2_2 = 19.172$, $P < 0.001$). For clarity, we examine the effect of partner IBI reactivity and dyadic pairings on covariation separately for high-risk and low-risk operations (Fig. 6).

Covariation in High-risk Operations

Within high-risk operations, all 3 dyadic pairings exhibited significant negative covariation—indicating that the more positive one person's physiological responses, the more negative the other person's responses at the same time. When comparing covariation between dyads, we found that the negative correlation in physiological reactivity between attending surgeons with residents—as attending surgeons increased reactivity, the resident exhibited decreased reactivity—showed the strongest association among all dyad pairings. Furthermore, operating room nurses showed significantly different covariation with residents compared with attending surgeons such that the more positive the resident reactivity, the more negative the operating room nurses' reactivity. The overall pattern of negative covariation seems to be driven by attending surgeons, whose IBI reactivity was negatively associated with reactivity from other team members, demonstrating that team members' responses diverged in high-risk operations.

Covariation in Low-risk Operations

In contrast to high-risk operations, attending surgeons and operating room nurses exhibited significant positive covariation, while residents did not show significant covariation with either attending surgeons or operating room nurses. The difference between residents' covariation with attending surgeons was not significantly different from covariation with operating room nurses. Operating room nurses' covariation with residents was significantly weaker than with attending surgeons. Together, attending surgeons' and operating room nurses' responses were synchronized, whereas the residents' responses were not correlated with the rest of the team.

DISCUSSION

Stress in the operating room is inevitable, yet surgical staff may cope with stress in different ways. In this study, we measured physiological responses of operating room teams during surgery. Continuous physiological measurement introduces a novel method of tracking stress responses intraoperatively, in situations in which team members respond dynamically to shifts in operative complexity, and indirectly, patient risk. We found that attending surgeons' physiological reactivity coincided with operative complexity—stronger reactivity occurring at moments of heightened complexity. Thus, attending surgeons were more attuned to patient risk in their physiological responses than residents and nurses. These findings imply that attending surgeons may adapt better to critical moments during surgery compared to other members of the team. Such physiological flexibility may be advantageous in the operating room, where operations can present unpredictable challenges that require staff to respond swiftly. For example, surgeons may experience increased arousal when attention is crucial and decreased arousal in the absence of cognitive demand. Thus, the attending surgeons' ability to flexibly exert effort when surgical demands are high and refrain from expending energy when it is not necessary, may be especially important in the highly stressful environment of the operating room.

Interestingly, attending surgeons and residents responded differently during surgery despite both groups having primary operator roles. This difference in physiological flexibility could be attributed to role responsabilities and expertise, which previous research has linked to greater arousal and better performance in stressful situations.[39,40] Although prior work has examined surgeons' stress,[3] this study provides further

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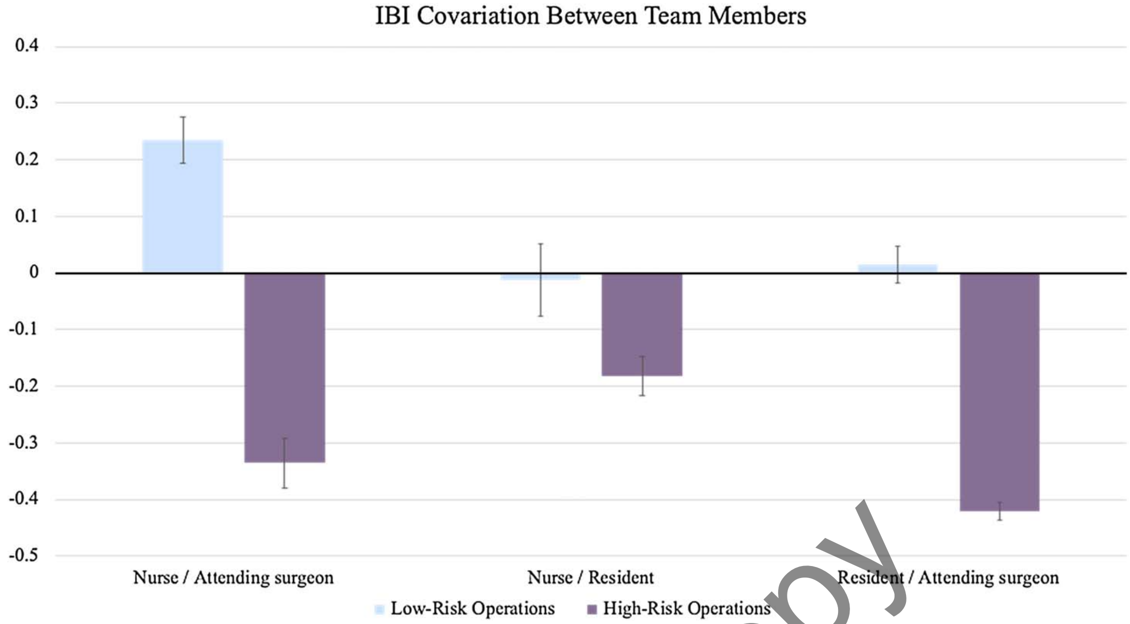

FIGURE 6. IBI reactivity by intraoperative risk. The values on the *y* axis represent the correlation between the dyad's IBI reactivity. Negative values indicate negative covariation (mismatched physiological responses), and positive values indicate positive covariation (synchronized physiological responses).

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perspectives and clarity by examining real-time intra-operative physiological responses across professional groups, as well as how these responses vary depending on the level of surgical risk.

Furthermore, we examined covariation—the co-occurrence of 2 individuals' physiological arousal in the same minute—between team members to assess whether teams' responses were synchronized during surgery. In low-risk operations, operating room nurses and attending surgeons showed positive covariation, suggesting that they responded similarly throughout the operation while the resident's responses were not correlated with either team member. In high-risk operations, team members showed negative covariation, indicating that as one member exhibited greater reactivity, their team members showed decreased reactivity. These complementary responses suggest that in high-risk operations, there is a trade-off in effort between team members; this trade-off is particularly notable between the attending surgeon and resident, who exhibited the strongest negative covariation. From a psychological standpoint, attending surgeons may be taking on the burden of the operation by narrowing their focus on the patient and signaling that they are in control and offering greater psychological security for the team.

Physiology is highly context-dependent and can represent various mental states and metabolic demands. To explore whether changes in reactivity reflect metabolic demand (metabolic demand would increase when one is actively operating on the patient compared with having a passive role and not engaging in any physical activity) or psychological stress (increased reactivity regardless of physical effort), we explored whether reactivity varied as a function of who was acting as the primary operator: the attending surgeon or the resident. Results indicate that attending surgeons exhibited greater reactivity while operating compared with when the resident was operating. This may reflect the greater stress posed by having overall responsibility for the case. Residents were similarly reactive regardless of whether they or the attending surgeon were the primary operator. This may mean that relatively lower experience levels resulted in uniform reactivity irrespective of operative demands. Nurses' reactivity was higher when the resident was operating (compared with the attending), suggesting that the attending performing the operation offers greater psychological security for the team. Although we cannot infer specific emotions from physiological reactivity,[37] these findings suggest that attending surgeons calibrated their responses to match psychological demands, whereas residents and nurses exhibited activation regardless of the risk of the surgery (see Appendix C for additional analyses, Supplemental Digital Content 1, http://links.lww.com/SLA/E797).

Renal replacement surgery can be lengthy and stressful, requiring constant attention. Physiological arousal, sustained over several hours, is associated with an increased risk of insulin resistance and cardiovascular risk.[9] While attending surgeons' ability to regulate their responses based on situational demands may be adaptive from a performance standpoint, high reactivity sustained over a long period of time may have detrimental effects on health and lead to burnout. Future research should investigate the longitudinal effects of reactivity on health outcomes.

LIMITATIONS

One limitation of this research is the insufficient self-report data. The small sample size prohibited us from analyzing individual differences (eg, differences in personality traits). It may be the case that certain personality traits enable people to cope with intraoperative stress, and future research should examine whether there are indeed trait differences in stress management. In addition, we attempted to measure anesthetists' physiology as part of the operating room team. Anesthetists frequently left the room which prevented the acquisition of continuous and reliable data from this professional group. Capturing whole-team data should be considered in future work, as anesthetists play an

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important role in the operating teams' performance. Furthermore, the operative context studied here is relatively narrow and work outside renal replacement surgery (eg, cardiac or neurosurgery) could shed additional understanding on operative team interactions. Last, we relied on minimally invasive sensors to measure IBI metrics, which limit our understanding of physiological reactivity in this context. Measures like impedance cardiography to measure cardiac output, continuous blood pressure measurements to obtain changes in hemodynamic responses, and real-time serum glucose levels would offer a more comprehensive portrait of stress reactivity among surgical teams.

Practical Implications

This study suggests that attending surgeons may experience greater risk perception during high-risk procedures compared with the remaining team members. Team members may not show the same sensitivity to risk, highlighting important discrepancies in awareness and readiness to respond to critical intraoperative events. Currently, patients benefit from extensive intraoperative physiological monitoring. This same level of surveillance is not available for surgeons, despite immediate implications for teamwork outcomes and a long-term impact on burnout and health. Our research highlights the importance of understanding real-time variations in the physiological performance of medical personnel.

Future research should focus on the impact of stress monitoring on error avoidance and improvement in team performance. This approach may be coupled with the real-time recording of intraoperative events using surgical "black boxes," which may facilitate team debriefing and retrospective analysis of intraoperative threats and errors.[38] Understanding these effects can help develop strategies to mitigate poor surgical outcomes and burnout.

CONCLUSIONS

Attending surgeons, as opposed to residents and operating room nurses, are more sensitive to shifts in demand in the operating room. Changes in the attending surgeons' physiological reactivity coincide with changes in patient risk. Other team members may be less attuned to the demands of the moment. These findings suggest that attending surgeons show more adaptive physiological responses under stressful conditions and have important implications for teamwork and workload management.

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