From the Society for Vascular Surgery

Intraprocedural ergonomics of vascular surgeons

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ABSTRACT

Objective: The objective of this study was to estimate the ergonomic postural risk (EPR) for musculoskeletal posture of vascular surgeons performing open and endovascular procedure types and with various adjunctive equipment using wearable inertial measurement unit (IMU) sensors. The hypothesis was that EPR will increase with increased physical and mental demand as well as with procedural complexity.

Methods: A prospective, observational study was conducted at a large, quaternary academic hospital located at two sites. Sixteen vascular surgeons (13 male) participated in the study. Participants completed a presurgery and postsurgery survey consisting of a body part discomfort scale and a modified NASA-Task Load Index. Participants wore IMU sensors on the head and upper body to measure EPR during open and endovascular procedures.

Results: Vascular surgeons have increased EPR scores of the neck as measured by the IMUs and increased lower back pain when performing open surgery compared with non-open surgery ($P < .05$). Open procedures were rated as more physically demanding. The use of loupes resulted in increased EPR scores for the neck and torso ($P < .05$), and they were significantly associated with higher levels of lower back pain during procedures ($P < .05$) as well as with higher levels of physical demand ($P < .05$). The use of headlights also resulted in increased subjectively measured levels of physical demand and lower back pain. In comparing survey responses with IMU data, surveyed physical demand was strongly and significantly correlated with the neck ($r = 0.61$; $P < .0001$) and torso ($r = 0.59$; $P < .0001$) EPR scores. The use of lead aprons did not affect EPR or most surveyed measures of workload but resulted in significantly higher levels of distraction ($P < .01$). The data presented highlight the potential of using wearable sensors to measure the EPR of surgeons during vascular surgical procedures.

Conclusions: Vascular surgeons should be aware of EPR during the performance of their duties. Procedure type and surgical adjuncts can alter EPR significantly. (J Vasc Surg 2020;■:1-8.)

Keywords: Ergonomics; Posture; Vascular surgeon

Increased attention on physicians' well-being has primarily focused on promoting engagement and preventing burnout. Procedure-based specialists, including surgeons, face additional occupational hazards, such as chronic pain and work-acquired musculoskeletal dysfunction. Previous studies have documented the prevalence of pain among those performing open surgery, laparoscopy, and robotic procedures.[1-6] In a previous study, we surveyed members of the Society for Clinical Vascular Surgery and reported a high prevalence of chronic pain among members.[7] The surgeon's discomfort and pain may lead to reductions in case volume, disability, and early retirement, contributing to the looming crisis in the vascular surgery workforce. Despite this, studies linking a practitioner's pain to intraoperative ergonomic posture are lacking. Vascular surgeons who perform open and endovascular procedures may be at particularly high risk for musculoskeletal dysfunction as they encounter the aggregate ergonomic risks of various procedure types and adjunctive equipment including surgical loupes, headlights, and lead aprons.

Long-term work-acquired musculoskeletal dysfunction has its genesis in poor surgical ergonomics, a problem that has proved difficult to characterize and ultimately to correct. This study provides insight into surgeons' intraprocedural ergonomics and posture using wearable inertial measurement unit (IMU) sensors.

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METHODS

Setting and participants. A prospective, observational study was conducted at a large, quaternary academic hospital located at two sites. Sixteen surgeon participants (fellows [n = 3], resident [n = 1], and attending surgeons [n = 12]) specializing in vascular surgery were invited to participate in the study. Surgeons were recruited by word of mouth, by presentation at a vascular surgery departmental meeting at one of the two hospital sites, and by e-mail and were informed of the requirements of the study before consenting. Participation was optional, and surgeons were instructed that they could opt out at any point of the study. Study results were kept anonymous as to not identify individual differences across surgeons. The study was approved by the Institutional Review Board, and informed consent was obtained before study participation.

Protocol overview. Participants completed a baseline survey consisting of a body part discomfort scale to assess pain, questions on demographics, job position, and years of experience. In addition, for each study surgical day, a presurgery and postsurgery survey consisting of a body part discomfort scale and a modified NASA-Task Load Index (TLX) was completed. Participants wore IMU sensors on the head and upper body to measure body position with respect to ergonomic risk during procedures. Data collection focused specifically on vascular procedures in the surgical listing, including lower extremity, miscellaneous, aortic, mesenteric, and cerebrovascular categories.

Surgeons were met by a researcher at the beginning of the day. The surgical cases included in this study were mostly first cases of the day; however, two cases per day by the same surgeon were captured for survey data in 10 instances and for IMU data in 1 instance. The surgery survey was partially completed before the procedure (presurgery survey) and finalized after the procedure (postsurgery survey). Surgeons donned the IMUs with the assistance of study staff after they were in their scrubs but before entering the operating room and wore them during the entire procedure under sterile gowns. Study staff met with the surgeons after surgery to retrieve the IMUs and to complete the survey.

Procedural data. During the procedure, study staff marked on a data collection sheet the time of key moments in the procedure, such as when the surgeon scrubbed in or out. Procedural data including equipment use (lead, loupes, headlight), procedure type (open, endovascular, hybrid), and procedural duration (ie, skin to skin duration) were also collected. Questions about procedural details were used to identify factors of difficulty for the surgeon.

Presurgery and postsurgery survey. The presurgery and postsurgery survey consisted of body part discomfort ratings. Body part discomfort was rated for the neck, shoulder (right and left), upper back, lower back, and wrist/hands (right and left) at three time points—before surgery, during surgery, and after surgery—with 0 meaning none and 10 being the worst. The during and after surgery sections were both completed during the postsurgery time point.

The postsurgery survey contained a workload section that was a modified version of a previously published workload survey, the validated NASA-TLX,[8] including two of six of its subscales (mental demand and physical demand), and two additional questions from the surgery TLX (How complex was the procedure? and How distracting was the operative environment?).[9] Participants were asked to rate themselves for each of the four questions. These four questions and their rating measurement scales are presented in Table I.

IMU data collection and analysis. Before the surgical procedure, members of the study team affixed the IMUs on the surgeon and ensured that the devices were properly calibrated using a calibration procedure consisting of standing upright with arms and fingers pointing downward and the thumb pointing forward, standing upright with both arms at 90 degrees of lateral elevation, and a final pose with both arms at 90 degrees of elevation in front of the body (forward flexion). The IMU (Emerald; APDM Inc, Portland, Ore) is a small (4.8 × 3.7 × 1.4 cm) sensor used to measure body posture angles by the fusion of data from the accelerometer, magnetometer, and gyroscope contained within each sensor.[10] Four sensors were placed on the surgeon (Fig 1): right upper arm, left upper arm, head, and upper torso. IMUs were secured in pockets attached securely to the surgeon's scrubs and placed in a headband on the back of the head. If the surgeon was wearing a headlight, a headband was not worn and the sensor was taped to the back of the headlight. While the surgeon performed the surgical procedure, IMU data were collected at 128 Hz and stored onboard the device. After the case, the

ARTICLE HIGHLIGHTS

- **Type of Research:** Multicenter, prospective, observational study
- **Key Findings:** Vascular surgeons frequently expose their bodies to high ergonomic risk during procedures. Open procedures and use of surgical adjuncts such as loupes and headlights exacerbate ergonomic risk to the neck and torso solely on the basis of posture. The use of lead aprons does not affect postural ergonomic risk.
- **Take Home Message:** Vascular surgeons should be aware of ergonomic risk during the performance of their duties. Procedure type and surgical adjuncts can alter ergonomic risk significantly.

Table I. Questions included in presurgery and postsurgery surveys, their corresponding scales, and scores

Survey question	Scale range	Score, mean (minimum-maximum)
1. How mentally demanding was the procedure? (NASA-TLX)	0 (very low) to 20 (very high)	14.8 (2.0-20.0)
2. How physically demanding was the procedure? (NASA-TLX)	0 (very low) to 20 (very high)	12.1 (2.0-20.0)
3. How complex was the procedure? (SURG-TLX)	0 (not very complex) to 20 (very complex)	15.3 (2.0-20.0)
4. How distracting was the operating environment? (SURG-TLX)	0 (very low) to 20 (very high)	5.0 (1.0-16.0)

SURG, Surgery; *TLX*, Task Load Index.

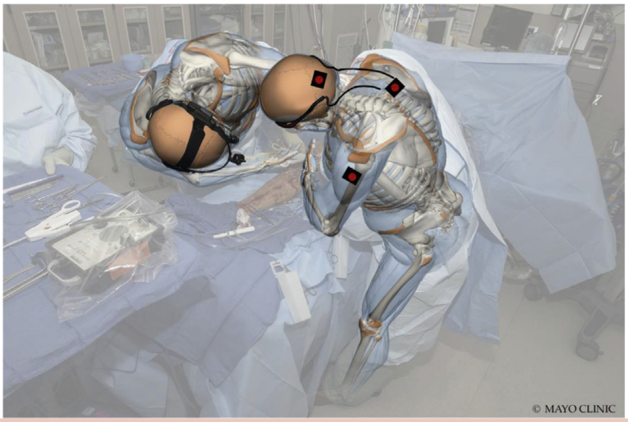


Fig 1. Schematic diagram illustrating a sample snapshot of surgeons' postures while using surgical adjuncts during a surgical procedure. (Image used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

IMUs were removed, and the data were downloaded by study team members and analyzed using an internal institutional program in MATLAB 2016a (MathWorks, Natick, Mass). If the calibration protocol was not satisfactorily performed before the start of the case, the corresponding data were not used in further analysis. The neck and torso angles were measured for the head and torso IMU data as deviations from the calibration posture. For the shoulders, the angles were measured as arm elevation relative to the calibration posture.[11-13]

Objective ergonomic risk. Objective ergonomic postural risk (EPR) was based on the amount of time the individual body segments were exposed to postures. The body angles were assessed and stratified into risk categories (minimal, mild, moderate, and high assigned with modified rapid upper limb risk assessment scores of 1.0, 2.0, 3.0, and 4.0, respectively) based on the measured body angles according to the modified rapid upper limb assessment.[14] For each procedure, the percentage of time spent in a specified range of risk categories for each body part, as shown in Fig 2, was calculated.

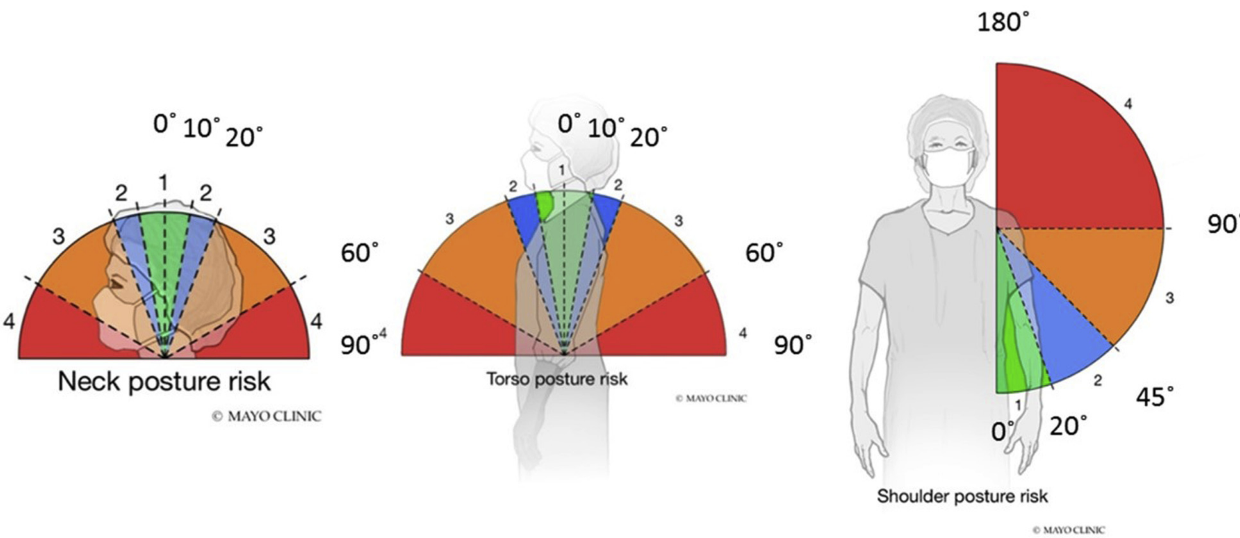
Statistical analysis. Descriptive statistical analyses were performed using SPSS (IBM Corp, Armonk, NY) and Microsoft Excel (Redmond, Wash) software. Ergonomic postural angles and risk were compared across procedure types (open, endovascular/hybrid) and equipment (loupes, headlight, lead apron). Specific comparisons were made between specific open but not non-open procedure categories because of the small sample size of non-open procedures. Linear mixed effect models using least square means examined differences in IMU-derived and survey-based outcome measures between procedure types as well as differences in risk scores between age groups (≤40 years, older than 40 years). Correlations were performed between workload questionnaire items and IMU-derived risk scores and between both discomfort ratings and postural duration with IMU-derived mean angle and risk scores with a type I error rate of .05. Data are presented as means with ranges.

RESULTS

A total of 16 surgeons (13 male) participated in the study. Data were collected for one to five cases per surgeon, with an average of three. Case durations ranged from 50 minutes to 9 hours and 15 minutes, with an average of 4 hours and 4 minutes. Eight surgeons were in the age group ≤40 years and performed 23 cases in total; the other eight surgeons were in the age group >40 years and performed 24 cases in total. IMU and survey data were successfully collected for 47 full cases. Body part angles and case duration for each procedure type and equipment use category are presented in Table II.

The percentage of procedural time that the neck, torso, and shoulder postures were categorized as minimal, mild, moderate, and high risk from the IMU data for all the vascular cases is shown in Table III.

IMU data showed the mean (minimum-maximum) neck EPR score for all cases to be 2.77 (1.80-3.36). Open cases had significantly higher risk compared with non-open cases (Table IV). There were no significant differences between the different open procedural types. The neck EPR score was also exacerbated by the



Risk Category	Neck Posture Risk	Torso Posture Risk	Right Shoulder Risk	Left Shoulder Risk
1 (minimal)	Deviation between 0° and 10°	Deviation between 0° and 10°	Elevation between 0° and 20°	
2 (mild)	Deviation between 10° and 20°	Deviation between 10° and 20°	Elevation between 20° and 45°	
3 (moderate)	Deviation between 20° and 60°	Deviation between 20° and 60°	Elevation between 45° and 90°	
4 (high)	Deviation >60°	Deviation >60°	Elevation >90°	

Fig 2. Schematic diagrams illustrating body angle ranges for minimal (1), mild (2), moderate (3), and high (4) risk categories for the neck, torso, and shoulder according to the modified rapid upper limb assessment. (Image used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

presence of loupes and lead aprons as the use of these tools was significantly associated with higher EPR scores (Table IV). No difference in neck EPR score was noted between cases involving the use of headlights and cases not involving headlights.

The torso EPR score for all cases was 2.07 (1.25-2.91), with a significantly higher risk for cases involving the use of loupes compared with cases not involving the use of loupes (Table IV).

The shoulder EPR score for all cases was 1.47 (1.11-2.16), with no significant differences observed between open and non-open procedural types or the use of loupes, headlights, or lead aprons (Table IV). However, significant differences were observed in the shoulder EPR score between the different types of open procedures (Table IV; $P = .0062$).

The survey responses for the measures of workload across all surgical cases are presented in Table I.

Lead aprons did make a significant difference in one of the subjective measures of workload. Collected survey data showed that surgeons wearing lead rated their level of distraction from the operating environment significantly higher (7.6 [1.0-16.0]) than surgeons not wearing lead (3.7 [1.0-15.0]; $P < .01$). No other categories of workload were significantly associated with wearing lead.

Survey data also showed that loupes and headlights were significantly associated with higher levels of lower back pain during procedures ($P < .05$). The pain rating for lower back pain with loupes was 3.2 (0.0-10.0) compared with 1.6 (0.0-6.0) without loupes. The pain rating with a headlight was 3.9 (0.0-8.0) compared with 2.2 (0.0-10.0) without a headlight. Surgeons reported a higher level of physical demand with loupes (13.6 [2.0-20.0]) than without loupes (10.0 [2.0-17.0]; $P < .05$) and a higher level of physical demand with headlights (16.1 [11.0-20.0) than without headlights (11.1 [2.0-18.0]; $P < .05$). Looking across procedure types, survey data showed that open procedures (12.8 [2.0-20.0]) were rated more physically demanding than endovascular/hybrid procedures (8.8 [2.0-20.0]; $P < .05$).

Table II. Angle for the neck, torso, and shoulders and case duration for procedure types, with and without surgical adjuncts

Category (No.)	Neck angle, degrees	Torso angle, degrees	Shoulder angle, degrees	Case duration, hours
Open (37)	41.9 (18.8-59.7)[a]	19.7 (10.8-33.6)	20.8 (12.1-37.6)[a]	4.2 (0.8-9.3)
Endovascular/hybrid (10)	23.8 (13.4-50.2)	14.0 (7.1-27.1)	18.8 (11.3-27.4)	3.5 (1.5-6.2)
Headlight (10)	36.9 (18.8-46.8)	18.6 (15.4-22.8)	20.8 (14.5-35.4)	5.5 (3.1-9.3)
No headlight (37)	37.1 (13.4-59.7)	18.1 (7.14-33.6)	20.2 (11.3-37.6)	3.7 (0.2-7.5)
Loupes (29)	40.8 (23.0-59.7)[a]	20.7 (10.7-33.6)[a]	20.1 (13.2-37.6)	4.4 (0.8-9.3)
No loupes (18)	31.5 (13.4-52.4)	14.4 (7.1-21.8)	20.6 (11.3-35.4)	3.6 (1.0-6.1)
Lead (16)	27.1 (13.4-54.7)[a]	16.3 (7.1-33.6)	19.5 (11.3-27.4)	3.7 (1.2-6.2)
No lead (31)	42.1 (18.8-59.7)	19.1 (8.6-33.6)	20.7 (12.1-37.6)	4.3 (0.8-9.3)

Values are presented as mean (range).
Cells are highlighted according to the ergonomic risk value associated with the mean angle value: *green*, minimal; *blue*, mild; *orange*, moderate; or *red*, high.
[a] P value $< .05$.

Table III. Percentage of procedural time that the neck, torso, and shoulder postures were categorized as minimal, mild, moderate, and high risk

	Neck	Torso	Shoulder
Minimal risk	8.9 (0.4-44.5)	28.9 (1.5-68.2)	56.5 (2.5-89.3)
Mild risk	12.2 (1.0-41.1)	30.2 (5.5-51.5)	35.2 (7.5-85.6)
Moderate risk	66.5 (10.5-92.8)	38.7 (0.8-92.3)	7.9 (0.2-45.9)
High risk	12.4 (0.0-48.3)	2.3 (0.0-53.4)	0.3 (0.0-10.2)

Values are presented as mean (minimum-maximum) percentage of time.

Longer procedural durations were significantly correlated with neck ($r = 0.36$ [$P = .014$]; $r = 0.30$ [$P = .042$]), right shoulder ($r = 0.35$ [$P = .017$]; $r = 0.32$ [$P = .034$]), and lower back ($r = 0.46$ [$P = .001$]; $r = 0.48$ [$P = .001$]) discomfort during and after surgery as well as with upper back discomfort during surgery ($r = 0.44$; $P = .002$). Longer procedural durations were also significantly correlated with increased discomfort in the neck ($r = 0.40$ [$P = .006$]; $r = 0.33$ [$P = .027$]) and lower back ($r = 0.38$ [$P = .011$]; $r = 0.77$ [$P = .011$]) from baseline to both during and after surgery and increased discomfort in the shoulders ($r = 0.25$; $P = .016$) and upper back ($r = 0.35$; $P = .010$) from baseline to during surgery.

In comparing survey responses to IMU-derived risk data, there were several correlations in the moderate to strong range. The strongest correlation occurred between surveyed physical demand and neck risk ($r = 0.61$; $P < .0001$), with the second strongest correlation between surveyed physical demand and torso risk ($r = 0.59$; $P < .0001$). All other correlations were nonsignificant ($P \leq .55$).

Weak and insignificant correlations of procedural duration with neck, torso, and shoulder ergonomic risk and also of procedural duration with neck, torso, and shoulder mean angles were observed ($P > .7$).

Mean procedural durations were significantly longer for the age group ≤40 years compared with the age group >40 years (296 vs 210 minutes; $P = .048$). Surgeons in the age group ≤40 years rated their level of distraction significantly higher compared with the age group >40 years (3.55 vs 6.90; $P = .045$). No other significant differences were observed in IMU-derived or survey-based outcome measures.

DISCUSSION

Recent publication trends reveal increasing interest in surgeons' well-being. A growing awareness of burnout, depression, and professional satisfaction among physicians and surgeons has resulted in a body of literature that supports efforts to improve emotional and mental health. Ironically, despite the obvious physical nature of surgery, efforts to address work-related musculoskeletal dysfunction are scant across all specialties. Furthermore, whereas there is a growing body of literature focusing on the ergonomics of surgeons during operations, there is a paucity of data in the vascular surgery literature. It is noteworthy that emotional and physical wellness may be linked; our previously reported survey of Society for Clinical Vascular Surgery members demonstrated a correlation between burnout and work-related pain, as did Society for Vascular Surgery workload.[7] This study represents the first effort to characterize the ergonomic issues encountered specifically by vascular surgeons.

Our data demonstrate higher objectively measured neck EPR scores as well as higher subjectively measured physical demand during open cases compared with endovascular cases. The measure of increased neck angle, especially in the open cases, can lead to increased strain on the cervical neck because of increasing weight

Table IV. Ergonomic postural risk (EPR) score for the neck, torso, and shoulders for procedure types, with and without surgical adjuncts

Category (No.)	Neck risk	Torso risk	Shoulder risk
Open (37)	2.94 (2.22-3.36)[a]	2.18 (1.57-2.91)	1.49 (1.11-2.16)
Endovascular/hybrid (10)	2.31 (1.80-3.12)	1.75 (1.25-2.67)	1.41 (1.11-1.82)
Open aortic/mesenteric (17)	2.88 (2.12-3.33)	2.26 (1.32-3.34)	1.45 (1.15-1.79)[a]
Open cerebrovascular (4)	2.94 (2.47-3.12)	2.30 (1.70-2.67)	1.31 (1.19-1.40)[a]
Open lower extremity (10)	2.88 (2.22-3.36)	2.23 (1.57-2.73)	1.62 (1.15-2.16)[a]
Open miscellaneous (6)	3.07 (2.66-3.35)	2.42 (1.77-2.54)	1.55 (1.30-1.88)[a]
Headlight (10)	2.85 (2.22-3.13)	2.17 (1.94-2.46)	1.50 (1.23-2.09)
No headlight (37)	2.76 (1.80-3.36)	2.05 (1.25-2.91)	1.46 (1.11-2.16)
Loupes (29)	2.91 (2.22-3.36)[a]	2.24 (1.49-2.91)[a]	1.46 (1.11-2.16)
No loupes (18)	2.57 (1.80-3.20)	1.82 (1.25-2.47)	1.48 (1.11-2.09)
Lead (16)	2.43 (1.80-3.33)[a]	1.91 (1.25-2.89)	1.44 (1.11-1.82)
No lead (31)	2.95 (2.22-3.36)	2.15 (1.33-2.91)	1.48 (1.11-2.16)

Values are presented as mean (range).
[a] $P < .05$.

of the head on the cervical neck with increasing neck angle.[15] In this study, the use of loupes was found to exacerbate objectively measured neck and torso risk and to result in increased subjectively measured levels of physical demand and lower back pain. The use of a headlight also resulted in increased subjectively measured levels of physical demand and lower back pain. Wearing a lead apron was found to double surgeons' subjectively measured level of distraction. Subjectively measured physical demand was moderately correlated with objective neck and torso risk scores, supporting the premise that prolonged postures in risky positions are perceived by the surgeon as an increase in demand.

In support of our findings, a previous study found that muscle activation (measured using surface electromyography [sEMG]) was significantly higher in surgeons during open surgery compared with laparoscopic or endovascular procedures, indicating higher risk ergonomic positions of the cervical neck and upper extremities. Their measurements were obtained between 30 minutes and 1 hour during the procedures rather than for the entire procedural duration as we did for this study. The postprocedure survey of musculoskeletal symptoms showed that surgeons experienced the most discomfort during open and laparoscopic procedures, especially in the neck.[16] Other studies have compared laparoscopic and robotic procedures as well as the experience level of the surgeons using sEMG and optical motion tracking.[17,18]

Video recording has also been used to measure rapid upper limb assessment scores of the neck, arms, and torso to assess the surgeon's posture on a laparoscopic box trainer to test the hypothesis that the surgeon's positioning during laparoscopic cholecystectomy can influence ergonomics.[19] More recently, a small number of studies by members of our team have used IMUs to measure high-risk ergonomic positions of surgeons. We found that IMUs are capable of measuring neck, torso, and upper extremity postures with comparable accuracy to an optical motion capture system ("gold standard") as surgical faculty members performed a standard simulated surgical training task mimicking minimally invasive surgery.[20] We then demonstrated the effectiveness of the IMUs at quantifying ergonomics in robotic prostatectomies,[21] for different chair types,[22] and during different postural positions in vaginal surgery[23] as well as for overall surgical specialties.[24]

This study is the first to present objective IMU-based postural measurements of surgeons during vascular surgery procedures. In addition, most studies to date have obtained ergonomic data by proxy, by either video recording of procedures, where the omission of data in the third dimension may lead to incomplete observational data, or sEMG data, which do not directly measure ergonomic positions but rather muscle load. Our study used IMUs, which allows direct body position measurement to determine body posture and associated EPR. In addition, the IMUs are small, lightweight, and functionally nonobtrusive so as not to influence the surgeon while measurements are being obtained.

This study is also unique in that it has quantified risk of surgical adjuncts, such as the use of loupe magnification and headlights, and their influence on EPR and musculoskeletal discomfort. In addition, the differences in body posture between open and endovascular cases have been quantified. Data were obtained for the entire duration of the surgical procedure instead of an incomplete sampling; therefore, complete procedural data can be examined instead of snapshots of the operation. This allows a more complete understanding of the amount of time participating surgeons spent in ergonomically high-risk positions during each procedure. Although the data suggest that procedural duration was not cross-sectionally associated with worse posture in our cohort, it was associated with higher levels of discomfort in a number of body part locations during and after surgery.

Limitations include the prospective data collection, the need of a trained researcher, the inability to determine the musculoskeletal demand of static postures based on IMU data alone, and the use of segment kinematics instead of kinematics across a joint, which is an active area of study for this group. In addition, there were too few cases involving the use of both loupes and a headlight and of hybrid cases to determine whether there are significant differences in their associated risk scores. The results from the comparison of cases involving the use of lead aprons to those involving no use of lead aprons may be masked by procedural type as lead aprons were worn for all 8 endovascular cases but for only six of the 37 open procedures. It is possible that merely participating in such a study may lead to magnification of reported discomfort. However, the large percentages of procedural time spent in moderately risky postures for both the neck and torso as objectively measured with the IMUs suggest that any magnification of discomfort may be minimal. Finally, the detrimental effect of longer duration of a case is not currently captured in the risk score. Future study will be needed to develop and to validate a duration-weighted risk score.

Further work with IMUs can identify ways of modifying surgeons' posture in the operating room to promote more time spent in ergonomically low-risk positions. Suboptimal loupe configuration resulting from poor fitting of loupes during fitting sessions can place an individual in a poor ergonomic position from the onset. There are also instances during portions of procedures that require poor ergonomic positioning, but not throughout the entire procedure. In addition, posture can evolve over time (either positively or negatively). We hope to incorporate an alert function into an IMU to improve posture during procedures by warning surgeons when they assume suboptimal positions, such as is used in other studies.[25] This may also be used during vascular and general surgery training to accelerate the learning curve of common operations and endovascular procedures.

CONCLUSIONS

Vascular surgeons are at increased risk of work-acquired musculoskeletal dysfunction and pain in the neck, torso, and shoulders when performing open surgery compared with non-open surgery and when using surgical adjuncts such as loupes and headlights. The data presented highlight the potential of using wearable sensors to measure the ergonomic risk of surgeons during vascular surgical procedures. Furthermore, they suggest that ergonomic risk may be altered by using different surgical techniques and tools.

AUTHOR CONTRIBUTIONS

Conception and design: VD, MM, BL, SH, SM
Analysis and interpretation: VD, AM, EF, MM, BL, AL, SH
Data collection: MM, SH
Writing the article: VD, AM, EF, MM, AL, SH
Critical revision of the article: VD, AM, MM, BL, SH, SM
Final approval of the article: VD, AM, EF, MM, BL, AL, SH, SM
Statistical analysis: EF, MM, AL, SH
Obtained funding: SH
Overall responsibility: VD
SH and SM participated equally and share co-senior authorship.

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