Measuring Ergonomic Risk in Operating Surgeons by Using Wearable Technology

The health care workforce faces numerous occupational hazards, leading to rates of injury and absenteeism that exceed those of the construction and manufacturing sectors.\(^1\)\(^2\) To date, efforts to address these problems have focused on improving safety for support staff, nurses, and allied health care personnel. Work-associated pain among surgeons has garnered less attention, despite the implications of practitioner injury and disability on the surgical workforce.\(^3\)

Ergonomists have long recognized the potential hazards facing the surgeon; from the ergonomic standpoint, surgery has been described as “a mess.”\(^4\) However, research has suffered from the absence of an objective means to measure surgeons’ ergonomic stress. This study describes the ergonomic risks of surgery using wearable sensor inertial measurement units (IMUs) to monitor the ergonomics of surgeons at work and identifies risk factors for injury.

**Methods** Preoperatively, surgeons had 4 IMUs placed on their head, torso, and upper arms to measure deviations from neutral body position. The IMU sensors measure body-posture angles via the fusion of data from an accelerometer, magnetometer, and gyroscope contained within each sensor. After processing, ergonomic risk was assessed by calculating the percentage of time spent in a specified range of risk categories for each body segment, facilitating stratification into ergonomic risk categories (Figure) using a validated scale.\(^5\)\(^6\)

The high-risk classification was based on occupational ergonomic research exposure-response analyses, which have shown clinically significant musculoskeletal disorders and/or discomfort associated with exposure to neck, torso, and arm postures in the high-risk categories. Objectively measured ergonomic risk was compared across procedure categories (eg, open, laparoscopic, and endovascular surgeries), adjunctive equipment (eg, loupes, headlight, lead apron), as well as surgeon characteristics (eg, including self-reported case complexity and physical discomfort using a preprocedure and postprocedure survey instrument). This study was approved by the Mayo Clinic institutional review board, and oral consent was obtained from all participants. The α level was set at 5%. Statistical analyses were performed using SPSS, version 26 (IBM), and statistical significance was set at a 2-tailed \(P < .05\).

**Figure. Measurement of Ergonomic Risk of the Neck, Torso, and Shoulder of Surgeons While Operating**

High-risk positions (categories 3-4; yellow and orange) for the neck (A), torso (B), and shoulder (C), with the mean (SD) percentage of time for categories 3 and 4 included.

**Table.** Placement of inertial measurement units and average percentage of time spent in specific postures

| Placement of IMUs | Average percentage of time spent in positions of ergonomic risk |
|-------------------|---------------------------------------------------------------|
| Head unit         | Neck position: 57 (22)% |
|                   | Shoulder position: 0.4 (0.7)% |
| Torso unit        | Torso position: 30 (22)% |
| Arm unit (left and right) | 0.3 (2)% |

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Table. High-Risk* Position Time by Surgical Specialty

| Surgical Specialty       | Total Cases, No. (%) | Mean (SD) Time in High-Risk Position, % |
|--------------------------|----------------------|----------------------------------------|
|                          |                      | Neck | Torso | Right Shoulder | Left Shoulder |
| Cardiothoracic           | 4 (3.5)              | 52.7 (32.0) | 20.6 (26.9) | 9.2 (9.2) | 6.7 (7.1) |
| Colorectal               | 11 (9.6)             | 50.9 (18.5) | 26.5 (17.5) | 6.3 (3.2) | 4.1 (4.8) |
| General                  | 25 (21.7)            | 59.6 (28.8) | 28.7 (22.5) | 9 (15.1) | 7.2 (12.5) |
| Gynecologic              | 10 (8.7)             | 61.2 (29.7) | 32.1 (27.7) | 13.2 (10.4) | 5.4 (4.1) |
| Head and neck            | 6 (4.4)              | 77.6 (19.1) | 25.7 (5.5) | 9.3 (4.9) | 6.1 (6.1) |
| Hepatobiliary            | 8 (7)                | 78.4 (27.1) | 34 (15.6) | 15.6 (17.4) | 6.7 (11.9) |
| Neurosurgery             | 5 (4.4)              | 60.4 (27.7) | 47.2 (35.0) | 14.9 (10.8) | 4.6 (4.4) |
| Orthopedic               | 7 (6.1)              | 69.1 (11.7) | 50 (25.7) | 13 (7.1) | 8.2 (2.2) |
| Plastic                  | 3 (2.6)              | 85.4 (9.8) | 31.4 (25.1) | 9.7 (4.8) | 4.7 (0.8) |
| Urology                  | 11 (9.6)             | 56.3 (23.1) | 21 (25.0) | 10.8 (14.7) | 6.4 (5.1) |
| Vascular                 | 25 (21.7)            | 71.5 (25.2) | 28.2 (21.2) | 7.3 (7.6) | 5.4 (9.0) |

*Categories 3 and 4.

Results | Fifty-three surgeons (19 women [35.8%]; mean [SD] age, 45 [11] years) representing 12 surgical specialties underwent continuous IMU recording during 115 cases (Table). Overall, surgeons spent 65% of procedure time in high-risk neck positions (Table; Figure, A). High-risk positions for the torso and shoulders were observed during 30% and 11% of the minutes of procedure time, respectively. The highest postural neck risk for surgeons was during open vs laparoscopic procedures (adjusted odds ratio, 31.1 [95% CI, 8.47-114.41]; P < .001).

The use of surgical loupes and headlamps were both independently associated with increased time in ergonomically unfavorable neck positions (mean [SD] with loupes, 85.2% [14.5%]; P < .001; without loupes, 58.1% [25.7%]; t110 = 5.11; P < .007; with headlamps, 79.9% [15.7%]; without headlamps, 62.2% [26.7%]; t105 = 2.42; P = .02). Risk factors for surgeon-reported pain included longer case length (F1,105 = 7.61; P < .001), increased years in practice (F2,84 = 4.42; P = .02), and use of loupes (t105 = 5.42; P < .001) and headlights (t105 = 2.75; P = .01). Surgeon self-reported pain was associated with ergonomic risk (F1,110 = 6.43; P < .01).

Conclusions | The physical demands of performing surgery are real. A surgeon’s cervical spine, in particular, is at unacceptably elevated risk during many procedures. Poor ergonomics are a cause of chronic pain and disability for many surgeons, reducing career longevity and threatening the public’s access to surgical care.3,4 This study demonstrates the utility of wearable technology as a means to assess surgeons’ intraoperative ergonomics and postural behavior, providing an evidence base and method for future objective research in this area. The limitations of the study include the sample size and selection bias inherent in selecting surgeon participants. Hopefully, this Research Letter encourages further investigation and induces surgeons to be mindful of their intraoperative ergonomics.

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According to federal statistics, mass shootings have tripled in the United States in the past decade. These mass-casualty events can easily overwhelm the resources of local hospitals. As the number of persons injured increases, even a well-prepared center can be pushed beyond capacity. While trauma systems have been established throughout the United States to prioritize getting the right patient to the right place at the right time, travel distance, traffic, casualty volume, and injury severity often result in transport of patients to a hospital that is not a trauma center (TC). It is hypothesized that the nearest available hospitals to mass shooting events will commonly be non-trauma center (NTC) hospitals, where such patient loads are more likely to overwhelm capacity and advanced care options may be limited. This study evaluates the location of recent mass shooting events relative to nearest hospitals and TCs.

**Methods** | Mass shootings, defined as events involving 5 or more injuries or deaths by a firearm, were documented from the Gun Violence Archive for the calendar year 2019. We defined a mass shooting as any having 5 or more individuals injured or killed by a gun, including the shooter; given our focus on system readiness, we selected patient burdens that would challenge the resources of TCs and NTCs alike. Using Google Maps, we calculated driving distance (in miles) from the geocoded address of the event to the nearest NTC (any hospital not verified as a level 1 or 2 adult or pediatric TC), adult level 1 or 2 TC, and pediatric level 1 or 2 TC. The TCs include all centers verified by American College of Surgeons and/or state entities. Hospital addresses were obtained from the American Hospital Directory. As a study involving only publicly available databases, this study was exempt, per the Children's Hospital of Philadelphia institutional review board and 45 CFR 46.104, and did not involve informed consent. Analysis was completed using Stata version 15.1 (StataCorp), and a \( P < .05 \) was considered significant.

**Results** | During 2019, there were 187 events occurring in 38 states. There were a total of 1250 individuals injured, with a