AUA **Update Series** 2021

Lesson 18 Volume 40

Ergonomics in the OR—What Surgeons Should Do to Protect Themselves and Others*

Learning Objective: At the conclusion of this continuing medical education activity, the participant will be able to:

- Identify the causes of and risk factors for work-related musculoskeletal disorders as they relate to surgeons in the operating room.
- Differentiate between modifiable and non modifiable risk factors for injury to surgeons and specific sources of muscle strain by route of surgery.
- Define existing ergonomic guidelines and recommendations for surgeons. Incorporate ergonomics guidelines and principles into individual surgeon practice and institutional training programs.

Tatiana Catanzarite, MD, MAS
Disclosures: Nothing to disclose

and

Shawn A. Menefee, MD
Disclosures: UpToDate: Article Author

Division of Female Pelvic Medicine and Reconstructive Surgery
Department of Obstetrics and Gynecology
Permanente Medical Group
San Diego, California

***This AUA Update addresses the Core Curriculum topic of Ethics, and the American Board of Urology Module on Core/General Urology.**

Accreditation: The American Urological Association (AUA) is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians.

Credit Designation: The American Urological Association designates this enduring material for a maximum of 1.0 *AMA PRA Category 1 Credits*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Other Learners: The AUA is not accredited to offer credit to participants who are not MDs or DOs. However, the AUA will issue documentation of participation that states that the activity was certified for *AMA PRA Category 1 Credit*™.

Evidence-Based Content: It is the policy of the AUA to ensure that the content contained in this CME enduring material activity is valid, fair, balanced, scientifically rigorous, and free of commercial bias.

American Urological Association
Education and Research, Inc.
1000 Corporate Boulevard
Linthicum, MD 21090

AUA Disclosure Policy: All persons in a position to control the content of an educational activity (ie activity planners, presenters, authors) provided by the AUA are required to disclose to the provider any relevant financial relationships with any commercial interest. The AUA must determine if the individual's relationships may influence the educational content and resolve any conflicts of interest prior to the commencement of the educational activity. The intent of this disclosure is not to prevent individuals with relevant financial relationships from participating, but rather to provide learners information with which they can make their own judgments.

Resolution of Identified Conflict of Interest: All disclosures will be reviewed by the AUA Conflict of Interest (COI) Review Work Group for identification of conflicts of interest. The AUA COI Review Work Group, working with the program directors and/or editors, will document the mechanism(s) for management and resolution of the conflict of interest and final approval of the activity will be documented prior to implementation. Any of the mechanisms below can/will be used to resolve conflict of interest:

- Peer review for valid, evidence-based content of all materials associated with an educational activity by the course/program director, editor and/or AUA COI Review Work Group.
- Limit content to evidence with no recommendations
- Introduction of a debate format with an unbiased moderator (point-counterpoint)
- Inclusion of moderated panel discussion
- Publication of a parallel or rebuttal article for an article that is felt to be biased
- Limit equipment representatives to providing logistics and operation support only in procedural demonstrations
- Divestiture of the relationship by faculty

Off-label or Unapproved Use of Drugs or Devices: The audience is advised that this continuing medical education activity may contain reference(s) to off-label or unapproved uses of drugs or devices. Please consult the prescribing information for full disclosure of approved uses.

Disclaimer: The opinions and recommendations expressed by faculty, authors and other experts whose input is included in this program are their own and do not necessarily represent the viewpoint of the AUA.

Release date: June 2021

Expiration date: June 2024

Key Words: ergonomics, operating rooms

ERGONOMICS AND WORK-RELATED MUSCULOSKELETAL DISORDERS IN THE OPERATING ROOM: DEFINING THE PROBLEM

What is ergonomics? The word "ergonomics" derives from the Greek *ergon* (labor) and *nomia* (arrangement). **Ergonomics is "the concept of designing the working environment to fit the worker, instead of forcing the worker to fit the working environment."[1]** Although some study of the interaction between humans and their work environments took place in ancient Greece, medieval medicine, and 19th century Poland and Germany, the field of ergonomics as an independent discipline emerged only after World War II. The Human Factors and Ergonomics Society was founded in 1957 with the mission "to promote the discovery and exchange of knowledge concerning the characteristics of human beings that are applicable to the design of systems and devices of all kinds."[2]

Ergonomic interventions have demonstrated benefits across a wide range of environments—from packing plants to sewing to hospital workers—leading to decreases in lost workdays and sick leave.[3] Ergonomic interventions can also improve workplace efficiency, reduce costs, decrease waste of materials and equipment, enhance corporate image, and increase employee satisfaction.[4,5]

What are work-related musculoskeletal disorders? **Work-related musculoskeletal disorders** are defined by the Centers for Disease Control and Prevention as "musculoskeletal disorders in which the work environment and performance of work contribute significantly to the condition; and/or the condition is made worse or persists longer due to work conditions."[6]

Because WMSDs have an enormous impact on absenteeism and productivity, they represent an important opportunity for ergonomic intervention. According to the Bureau of Labor Statistics, WMSDs in the private sector resulted in 27.2 cases per 10,000 workers in the United States in 2018; on average, WMSDs required 12 days for return to work.[7] The economic impact of WMSDs, accounting for lost wages, compensation costs, and lost productivity, is estimated by the National Academy of Medicine to be $45 to $54 billion/year.[6]

Prevention of WMSDs relies on avoidance of 7 specific high-risk activities:[8]

- Repetitions, defined as cycle <30 seconds or 1 basic activity element present for >50% of total cycle time
- Prolonged or repetitive exertion of >30% of the operator's strength
- Body segments held in an extreme position
- Prolonged static posture
- Activities with vibrating tools
- Exposure to cold
- Combinations of the above conditions

Several of these high-risk activities are common during surgery, including repetitive movements that require significant force on the trunk and upper extremities, and extreme, awkward, or prolonged static body positioning. As long as the surgeon stands with correct alignment, prolonged standing is not necessarily injurious. However, standing activities that involve outstretched arms, lifting, or other forces must be counterbalanced by the spinal muscles and may cause strain. In order for workers in any industry to reduce the risk of occupational low back pain, experts recommend 1) keeping extremities close to the body, 2) using a compliant mat underneath the feet to decrease spinal disc impact, and 3) alternating between sitting and standing.[9] Trunk rotation is a significant causal factor in low back pain; this is a common problem for laparoscopic surgeons, who often adopt twisted postures, sometimes as a result of incorrect monitor position.[10]

WMSDs associated with performing surgery are common across surgical specialties and modalities, and significantly impact productivity. Despite this, few formalized ergonomics programs have been implemented for surgeons.[11] This may relate in part to the underreporting of surgeon injuries to institutions,[12–14] as well as the challenges of studying surgical ergonomics in the live operating room setting due to equipment and sterile field limitations.[15]

PREVALENCE OF WORK-RELATED MUSCULOSKELETAL DISORDERS AMONG SURGEONS

A recent systematic review and meta-analysis evaluated 21 articles reporting **prevalence of WMSDs among surgeons and medical interventionists,** with the majority of the articles from general surgery, urology, and gynecology.[16] Pooled prevalence estimates were 17% for degenerative cervical spine disease, 18% for rotator cuff pathology, 19% for degenerative lumbar disease, and 9% for carpal tunnel syndrome during surgeons' careers. From 1997 to 2015, cervical and lumbar spine disease among surgeons increased by 18% and 27%, respectively,[16] a situation that has been identified as "an impending epidemic."[17] The impact on surgeon practice is impressive—12% of physicians with WMSDs take a leave of absence, modify their practice, or opt for early retirement.[16]

Survey-based studies show that 56.5% to 94% of surgeons reported discomfort related to open surgery.[12,18–24] Pain is typically in the hands, arms, neck, back, and shoulders.[12,18] **Among 561 spine surgeons, 7.1% had undergone surgery for lumbar disc disease and 4.6% for cervical disc disease; 31.9% took time off from work for musculoskeletal disorders.[23]** Among American College of Surgeons members, 40% had sustained a WMSD; although 50% had received medical care for WMSDs, **only 19% reported them to their institutions.[14]** Surgeon underreporting of injury may relate to a belief that pain and discomfort are an inherent "cost of the job"[25] in a field centered around patient care, not surgeon comfort. **Surgeons commonly report that they "continue to work through the pain** so that the quality of their work w[ill] not suffer."[12] WMSDs from open surgery can lead to time off work, decreased caseload, or early retirement.[14,20,23]

ABBREVIATIONS: EMG=electromyography, RALS=robotic-assisted laparoscopic surgery, TLS=traditional laparoscopic surgery, WMSD=work-related musculoskeletal disorder

Several studies have reported high rates of WMSDs related to endourological procedures. In one study of 121 urologists, 69% reported musculoskeletal disorders related to endourological transurethral resection of the prostate or laser prostatectomy.[26] The most common areas of pain were the neck, back, shoulder, and hand. Five surgeons (4.1%) reported having needed to **stop a surgery or postpone subsequent surgeries due to pain.** Surgeons reported treatments including ice/heat/stretching (53%), nonsteroidal anti-inflammatory medications (20%), and muscle relaxants (11%) to help with surgery-related pain.

Another study found that hand/wrist problems were reported by 32% of endourologists, with 85% of affected surgeons requiring either medical or surgical intervention.[27] In a worldwide survey of 764 urologists, 24% reported neck pain and 35% back pain. Of those with pain, 47% believed urological practice to be the cause; 60% underwent noninvasive treatments (physical therapy, massage, and acupuncture) and 25% underwent invasive treatments (injections or surgery) for pain.[28]

An international survey study found that 86% of urologists had experienced musculoskeletal complaints in the past year; 48.8% experienced chronic complaints, most commonly in the neck, back, and shoulders.[29] Endourology (OR 3.06) and traditional laparoscopic surgery (OR 1.7) were risk factors for chronic symptoms. WMSDs attributable to endourology and TLS required leaves <1 week in 3.9% and 5% of surgeons, respectively; another 3.9% and 2.8% required leaves >1 week due to endourology and TLS, respectively. Although most surgeons (89.9%) felt ergonomics were important, **only a third rated their knowledge of ergonomics as "good" or "excellent,"** with the remainder reporting "fair" or "poor" knowledge.-

For TLS, survey-based studies report WMSD prevalence between 73% and 100%, with the most common sites of injury being the neck, back, shoulder, elbow, and wrist.[13,17,30–33] In a study of 244 gynecologic oncologists, 88% reported discomfort from minimally invasive surgery; 29% underwent treatment and 9% modified their practice due to pain. **Only 1% had reported pain to their institutions and only 16% had ever received formal training in ergonomics.[13]** Among European Association for Endoscopic Surgery members, all respondents believed operating room ergonomics were important, but only 11% were aware of published guidelines.[33]

A recent systematic review of 35 articles reported that, **among surgeons performing minimally invasive surgery, the prevalence of musculoskeletal disorders was 74%**, which the authors note is considerably higher than the prevalence of such disorders in the general population. Of surgeons with WMSDs, **27% developed chronic pain,** most commonly in the neck (53%), back (51%), shoulders (51%), and hands (33%).[24]

The same systematic review reported that in 7 studies, **the prevalence of musculoskeletal complaints associated with robotic-assisted laparoscopic surgery was 56%, with chronic WMSDs in 5% to 11.9%** of surgeons.[24] The most common sites of discomfort from RALS were the neck and hand/wrist region, including the thumb and fingers. Respondents preferred RALS to open surgery and TLS, and felt there was an ergonomic benefit to robotic surgery. In one study cited, among surgeons who suffered from WMSDs, 8.3% attributed their musculoskeletal complaints to robotic surgery, 36.3% to open surgery, and 55.4% to TLS.[24]

Robotic surgery is perceived by surgeons to be associated with less wrist, neck, back, hip, knee, ankle, foot, shoulder, and elbow pain than open or laparoscopic surgery.[34,35] However, robotic surgery may be associated with increased finger pain and eye strain compared to other modalities, and also commonly produces pain in the neck and hand.[34,35]

In one of the few available interventional studies, Franasiak et al reported that among 42 robotic surgeons, 45% experienced pain, including 26% with persistent pain.[11] Two surgeons experienced pain that prevented them from carrying out normal activities and 3 sought medical care; **none had reported injuries to their institutions. Only 17% had previously received ergonomic training. After in-person training, 88% changed their practice and 74% reported decreased pain.** Training adjustments included proper chair position to allow 90 degree knee flexion, forearms parallel to the ground with elbows tucked at the side, head flexion <20 degrees, minimizing forehead pressure on headrest, and clutching frequently.[11]

COST OF SURGEON WMSDs

While the literature regarding cost of WMSDs among surgeons is limited, we do know that it has **major implications regarding caseload, practice patterns, and career longevity.** Among minimally invasive surgeons, 16% to 34.8% report that WMSDs affect surgical performance and 6.7% to 17% report decreasing their surgical caseload as a result of WMSDs.[24] In one study, 22% of surgeons reported missing workdays due to WMSDs with an average of 7 days per surgeon injury, and 35% reported performing fewer procedures after their injury.[14] In another study, 9% of surgeons performing minimally invasive procedures reported stopping their surgical practice due to WMSDs.[20] Up to 25% to 30% of surgeons consider musculoskeletal discomfort when planning their operative route.[36] For instance, surgeon injury may necessitate switching from minimally invasive to open techniques, negatively impacting patient recovery times and access to advanced techniques.[25]

Of 56 surgeons in a study by Hallbeck et al, **80% reported pain in the past day, with 41% reporting that pain interfered with relations with others, 51% reporting that it interfered with sleep, and 40% reporting that pain would influence their ability to perform or assist with surgical procedures** in the future.[25] Interference with sleep due to pain, as well as the ongoing pain itself, can compromise task performance, accuracy, and ability to process and confront unexpected events (such as a surgical complication), all of which may impact patient safety.[25]

As stated by Dalager et al, "from a societal perspective, [the truncated careers that can occur as a result of musculoskeletal injury] may be problematic since it takes many years of education to become skilled for highly specialised surgical procedures."[37] That is, training surgeons is expensive, and this must be factored into the **cost of sacrificing surgeons' health and career longevity due to suboptimal ergonomics**.

RISK FACTORS FOR WMSDs IN THE OPERATING ROOM

Operating room factors. General **ergonomic hazards in the operating room** include inadequate **lighting,** lights that collide or require **adjustment with one hand, tripping** hazards, uncomfortable postures while holding **retractors,** and pressure areas from **instruments.[18]** The **height of the operating room table** is critical; incorrect table height creates ergonomic risk to the back and neck as surgeons contort to view the operative field.

Prolonged static positioning also contributes to musculoskeletal strain.[38]

Although this has not been addressed for surgeons specifically, lifting patients is known to create significant ergonomic risk and is a major source of musculoskeletal disorders among nurses, particularly when moving overweight and obese patients. An expert review regarding WMSDs among nurses recommended **utilizing lifting/transfer equipment, no-lift policies, and ergonomic training and education.[39]** The **surgical team should be aware of ergonomic risk during patient transfers** and should consider the following: **proper table height and body posture, appropriate beds** for patient position and stature, utilization of **equipment** such as inflatable transfer systems, and **lifting teams** to distribute weight load, particularly for overweight and obese patients. **Further research is needed to identify unique ergonomic concerns during patient transfers in the operating room and to develop specific recommendations for safe transfer techniques.** In survey studies, surgeons identified multiple causal factors of discomfort, including footswitches, devices connecting equipment to the tables, insufficient lighting, hard-to-hold instruments, excessive table height or width, static or awkward postures, repetitive movements, and the use of loupe magnification, head-mounted lamps, and microscopes.[12,18,20,22]

Surgeon factors. **Risk factors for WMSDs** identified in survey studies include **younger age, hand-assisted technique, shorter surgeon stature, female gender, smaller glove size, higher patient or surgeon body mass index, surgeon medical comorbidities, and higher surgical volume.[13,17,28,32,36,40]** Factors that may be **protective** for laparoscopic surgeons include **awareness of ergonomics, exercise, greater number of years in practice, and older surgeon age.[13,29,30,32]**

According to a systematic review of minimally invasive surgeon ergonomics by Alleblas et al, **10 studies reported on surgeon experience and age,** with most studies finding that **less experience and/or younger surgeon age** was associated with greater musculoskeletal complaints.[24] **Most studies (6 of 8) found increased surgical caseload to be related to WMSDs,** for both TLS and RALS.[24]

UNIQUE ERGONOMIC PROBLEMS IN ENDOUROLOGY

Endourological procedures are associated with **prolonged static positioning and repetitive movements,** creating a high-risk ergonomic situation. One study identified 2 major risk factors for WMSDs after endourological procedures: **surgeon medical conditions,** such as arthritis, and, for prostate resections, **prostate size.** Operations with larger prostate size were associated with both occurrence and severity of WMSDs. Number of surgeries, standing versus sitting position, corrective eyewear usage, type of working element, and type of monitor did not affect risk of WMSDs.[26] Unique ergonomic risks by surgical modality, including endourology, are summarized in Appendix 1.

UNIQUE ERGONOMIC PROBLEMS IN TLS

Compared to other surgical approaches, **TLS creates unique musculoskeletal risks** for surgeons.[32] First, **static positioning of the head and trunk with less weight shifting** compared to open surgery places strain on the neck and back.[41,42] Second, the **fulcrum effect created by long laparoscopic instruments** requires exaggerated arcing movements to accomplish even fine movements in the surgical field.[43–46] Most operating room tables were designed for open surgery, so **tables are too high** to accommodate laparoscopic instruments, forcing surgeons to stand on platforms or utilize excessive arm abduction. **Platforms** frequently cannot accommodate electrosurgical **foot controls,** requiring surgeons to stand on one foot and reach for pedals.[46] In the systematic review by Alleblas et al, **incorrect monitor height and position, table height, and use of foot pedals were identified as a cause of WMSDs** in 8 studies.[24]

These problems are compounded **by poor ergonomic design of laparoscopic instrument handles, which require exaggerated ulnar deviation, wrist flexion, and arm abduction in order to place the thumbs in handle loops.[43, 47, 48]** Increased forearm and thenar muscle force is required for laparoscopic compared to open knot-tying and grasping tasks, and increased deltoid muscle effort is required for laparoscopic knot-tying.[49,50] Pressure areas from suboptimal handle design can lead to compression of the digital nerve of the thumb, causing paresthesias and neuropraxia commonly enough to have been dubbed **"laparoscopic surgeons' thumb."[18,47,49,51–53]** In one study, 36% of surgeons reported pressure areas, 26% neuropraxia and 57% uncomfortable body posture related to instruments.[18] According to the Alleblas systematic review, 12 studies have examined laparoscopic instruments as they relate to surgeon ergonomics; **handle design was reported as a cause of pain by 49% to 83% of surgeons.[24]**

Laparoscopic surgery also causes **greater eye strain than open surgery.[53]** Cuschieri described an anecdotal entity called "surgical fatigue syndrome" beginning after approximately 4 hours of continuous TLS; this syndrome is characterized by "mental exhaustion, increased irritability, impaired surgical judgment, and reduced dexterity" due to the ergonomic insults of laparoscopy.[54]

UNIQUE ERGONOMIC PROBLEMS IN RALS

Many have touted the robotic surgical platform—with its **advances including 3-dimensional immersive optics, scaling technology, wristed instruments with increased degrees of freedom, and seated surgeon position**—as the answer to many of the inherent ergonomic pitfalls of TLS. However, the **reality is somewhat more nuanced.** As we will see in the comparative studies in the next section, RALS does offer many advantages compared to TLS. However, it has also **introduced ergonomic issues of its own.** For instance, **prolonged sitting without appropriate lumbar support** creates more intradisc strain than standing,[9] and the **robotic console viewing angle is restricted to 40 to 60 degrees,** requiring a flexed posture that causes strain in the neck and trunk.[55]

A study utilizing sagittal photographs to calculate joint angles at the trunk, neck, shoulder, elbow, hip, and knee determined that during RALS, surgeons were outside optimal ranges for all body areas, especially the trunk, neck, and shoulder.[56] Harmful angles at the neck and trunk occur due to limitations of the console viewer angle. Based on the currently available console settings, the authors determined that **surgeons <175 cm (68 inches) in height cannot place the armrest at a suitable height for ergonomic positioning.** Likewise, **optics height can only be adjusted into an acceptable range for surgeons who are 155 to 200 cm (61–78 inches)** to be seated in a neutral position.

COMPARISON OF SURGEON ERGONOMICS DURING TLS VERSUS RALS

Multiple studies have compared surgeon ergonomics of TLS and RALS, utilizing research tools including 1) structured questionnaires of surgeon mental and physical workload, discomfort and fatigue, 2) posture analysis, 3) objective measures of fatigue, such as postoperative hand grip and single leg balance tests, and 4) electromyography, which is useful in quantifying muscle exertion and fatigue. A systematic review by Dalager et al[37] and a subsequent meta-analysis by Hislop et al[55] provide an **excellent summary of the available literature utilizing structured questionnaires to assess surgeon ergonomics in TLS versus RALS.** A total of 7 studies have evaluated surgeon mental and physical workload using the **NASA task load index (NASA-TLX),** which is divided into subscales including physical demands, frustration, effort, performance, temporal demands, and mental demands. **One study found no difference between TLS and RALS, while the other 6 significantly favored RALS with regard to the physical demands subscale.** Several studies also found benefits for RALS in the following subscales: stress, frustration, mental demands, and total workload. In contrast, validated questionnaires of surgeon physical discomfort have yielded inconsistent results, **with several studies favoring RALS but several others finding no difference in discomfort between RALS and TLS, with neck strain predominating for RALS and back strain for TLS.[37]** With regard to surgeon-reported fatigue, one study found no difference between TLS and RALS,[57] while another study comparing TLS versus RALS and primary versus assistant surgeon found that the **greatest mental fatigue occurred for the primary surgeon after RALS.[58]**

Hislop et al compiled the findings of 10 studies utilizing EMG to compare muscle activity during TLS and RALS; 5 studies collected data from real-time surgery and 5 from simulated tasks.[55] The authors report high levels of study heterogeneity and bias, and also note, importantly, that **when surgeons are queried subjectively, their responses consistently favor RALS to a greater degree than do objective tests.**

As reported by Hislop et al, EMG studies have demonstrated that **RALS requires significantly lower muscle effort at the biceps,** likely due to forearm support and lightweight controls.[55] EMG findings **also favored RALS throughout the upper arm muscles, with the exception of the thenar compartment.** TLS showed a non significant **trend toward requiring less muscle effort at the erector spinae muscles of the back as well as the thenar compartment** of the hand. The authors hypothesized that excessive trunk flexion due to improper chair position may be responsible for back strain during RALS. **Trapezius muscle activation was equivalent** for TLS and RALS.

An EMG-based study of fatigue showed that **more forearm muscle fatigue occurred during TLS compared with more neck and shoulder fatigue during RALS;** however, neither modality was clearly superior and overall fatigue was similar for both.[57] Significantly **more gaps per minute**—short periods of muscle rest >200 ms, which are protective against musculoskeletal disorders—**were noted in one study in the neck and trapezius muscles for RALS** versus TLS.

González-Sánchez et al assessed **surgeon fatigue** utilizing validated **questionnaires** and objective measures, including **hand grip and single leg balance tests** before and after surgery.[58] They found **higher levels of surgeon-reported mental fatigue and objectively measured functional fatigue after RALS.** These authors hypothesized that the static seated position of the surgeon, with minimal capacity for movement outside of the console, was one of the main contributors to surgeon fatigue during RALS.

A phenomenon of **ergonomic drift** was noted by Dalsgaard et al for both TLS and RALS—that is, **surgeons tended to "forget" ergonomic good habits during surgery.[59]** For TLS, twisted trunk position and reaching for foot pedals were common ergonomic errors. For RALS, surgeons used arm support less as the operation went on, and tended to roll farther away from the console, leading to increasing flexion of the back and arms. Finally, inadequate clutching of robotic controls contributed to excessive shoulder abduction and flexion. Based on the above studies, it is clear that, while RALS offers some ergonomic benefits over TLS, significant ergonomic risk remains, making it essential for surgeons to be aware of ergonomic guidelines in order to avoid injury.

ERGONOMIC GUIDELINES, INTERVENTIONS, AND NOVEL INNOVATIONS

Multiple authors have published ergonomics guidelines and recommendations for surgeons. **Current ergonomics recommendations** for operating room equipment and setup are summarized in Appendix 2, while those for surgeon posture and intra- and postoperative interventions are summarized in Appendix 3.

In order to facilitate proper ergonomic positioning according to these guidelines, **novel devices have been developed for surgeons.** A semi-standing support for the surgeon was shown to reduce EMG activity in several muscle groups.[60] Conceptualization and prototype testing were reported for a **below-the-elbow arm support** to reduce arm strain during TLS.[61] **An adjustable chair,** developed for use in TLS, has also been described.[62]

Static muscle posture during surgery exacerbates muscle fatigue and reduces motor control and strength.[58] Accordingly, microbreaks—short breaks of about 1 minute more than once per hour—are an intriguing protective intervention for surgeons. Microbreaks and exercise have been shown to reduce WMSDs in other settings, such as computer tasks, leading to recommendations for stretching and rest breaks throughout the workday.[25] Engelmann et al demonstrated that **intraoperative breaks** (5 minutes every 30 minutes) during TLS significantly **decreased surgeon stress,** as measured by salivary hormone levels, cardiac monitoring, and questionnaire responses, without increasing operative times.[63] Dorion and Darveau reported that micropauses (20-second break every 20 minutes) **reduced surgeon fatigue and muscle discomfort;** micropauses were also associated with a **sevenfold reduction in errors on a precision task** after surgery.[64] Hallbeck et al reported on longer microbreaks, described as 1.5- to 2-minute guided exercises performed at medically convenient 20- to 40-minute intervals.[25] Among a multicenter, multispecialty cohort of surgeons, microbreaks were associated with **decreased shoulder discomfort and improved surgeon-reported physical performance.** Surgeons reported minimal distraction or interruption of surgery flow from microbreaks, and **87% wanted to incorporate microbreaks** into practice.

In a randomized controlled trial by Giagio et al, surgeons randomized to a **preventive program** including following ergonomic principles and specific exercises under the guidance of a physical therapist had a significant **improvement in health-related quality of life, low back pain, and analgesic use** after 6 months.[65] Very recently, Dalsgaard et al published their **Copenhagen Recommendations for surgeon ergonomics in minimally invasive surgery,** which have been incorporated into Appendixes 2 and 3 of this Update.[59] The authors recommend that surgeons not only familiarize themselves with these ergonomic principles, but also undergo **ergonomics-directed observation and training semiannually or annually.** Furthermore, they join with previous authors in recommending that trainees receive ergonomics education as part of surgical training programs.

CONCLUSIONS

Surgeons suffer from **high rates of work-related musculoskeletal disorders** across specialties and modalities of surgery. As in other fields, surgeon WMSDs lead to **time off work, modification of practice and, in some cases, early retirement. Underreporting** of surgeon injury to institutions and **low levels of surgeon awareness** of ergonomics recommendations serve to reinforce this problem. Continued development of **evidence-based guidelines and ergonomics training** for surgical trainees and practicing surgeons should be prioritized in order to **prevent surgeon injury, improve patient care and protect career longevity.**

DID YOU KNOW?

- WMSDs among surgeons are extremely common for all modalities of surgery covered in this Update, including open surgery, endourology, TLS and RALS.
- Surgeons are very unlikely to report injury to their institutions and also very unlikely to have received specific training in ergonomics.
- There are unique risks to the surgeon depending on the route of surgery. Risk factors associated with open surgery include retractors and use of loupes, microscopes, and headlamps. For endourology, larger prostate size is associated with surgeon injury. For TLS, long instruments, excessive table height, improper monitor position, and suboptimal handle design create ergonomic risk. Finally, for RALS, eye strain, prolonged static positioning, and inappropriate console and chair settings all contribute to ergonomic risk.
- Surgeon WMSDs lead to missed work, modifications of practice including changes to surgery modality and reductions in caseload, and in many cases, early retirement from surgical practice.
- Ergonomics guidelines are available for surgeons; awareness of and training in ergonomic principles have been shown to benefit surgeons. Similarly, microbreaks—short intervals of movement and/or stretching occurring more often than once per hour during surgery—can decrease surgeon pain and fatigue.

Appendix 1. Unique ergonomic concerns and risk factors by modality of surgery

Modality	Ergonomic concerns
General operating room factors	Inadequate lighting Lights that require adjustment with one hand frequently during surgery Tripping hazards Operating table variables—too wide, too high, or difficulty maneuvering with obese patient/improper arm positioning Footswitches requiring surgeon to stand on one foot to reach/operate
Open surgery	Prolonged static positioning Use of retractors Use of surgical loupes, headlamps, microscopy, leading to increased neck flexion
Endourology	Prolonged procedures Repetitive movements Settings of adjustable visual terminal workstation
Traditional laparoscopic surgery	Poor ergonomic design of instrument handles Static positioning of head and trunk, less weight shifting compared to open surgery Fulcrum effect of long instruments rotating around fixed trocars Standard operating room tables may not lower adequately for laparoscopy Eye strain from looking at monitors Inappropriate monitor position, leading to excessive twisting or improper neck postures
Robotic-assisted laparoscopic surgery	Prolonged sitting Tendency of rolling chair to move farther from console throughout surgery Poor surgeon awareness of correct console settings, leading to excessive back and neck flexion Constraints of viewing angle (40–60 degrees) and console adjustment range

Appendix 2. Guidelines and recommendations regarding equipment and operating room setup to optimize surgeon ergonomics

Equipment Type	Recommendation
Operating room setup	Consider use of compliant antifatigue mats Lace covers or mats on top of cords to reduce tripping hazards Adjust overhead lights prior to start of case to avoid light adjustment while maintaining sterile field
Monitor position	Top of laparoscopic monitors should be at or below surgeon eye level Image should be 15–45 degrees below eye level Screen height of 160 cm is recommended
Table height	Adjust table height to the tallest surgeon with step stools used for other team members For laparoscopy, adjust body of patient to 10–15 cm below the surgeon's elbow, with operating table between a factor of 0.7 and 0.8 of surgeon's elbow height
Standing support	Standing support adjustable between 80–100 cm may help prevent prolonged static standing posture
Arm boards	To avoid trunk twisting, tuck patient's arms whenever possible
Foot pedal position	Arrange pedals such that surgeons can reach them without balancing on one foot Place foot pedals next to foot in line with target instruments toward the target quadrant
Robotic console	In robotic surgery, utilize a chair that cannot slide or roll back, as this can inadvertently increase back flexion Adjust and save workstation settings to body dimensions in the following order: 1. Chair height 2. Chair close to console 3. Forearm support 4. Head support height 5. Head support angle 6. Pedals
Instruments	Should not require more force than 15 N to completely close

Adapted with permission from Catanzarite et al (2018).[66] Incorporates 2020 Copenhagen Recommendations.[59]

Appendix 3. Ergonomics recommendations regarding surgeon body posture, intraoperative, and postoperative interventions, listed by applicable body site

Body Part	Recommendation
General	Move as much as possible Take short breaks (suggest 1.5- to 2-minute breaks every 20–40 minutes when medically convenient) with intraoperative stretching Maintain awareness of work postures throughout surgery
Shoulder/upper arm	Upper arm should remain perpendicular to floor and held close to the surgeon's body Shoulders should be dropped and hands relaxed Shoulder abduction should be <30 degrees. Arms should be slightly abducted and rotated inward Assistants should rotate responsibility for retraction to avoid prolonged strain for any individual
Forearm/elbow	Elbows should be held between 90 degrees and 120 degrees flexion To avoid excessive elbow flexion/extension, hold forearm in horizontal position, parallel to the floor To avoid excessive torque, maintain forearm in neutral position between supination and pronation Utilize forearm support in robotic surgery with frequent clutching to maintain optimal arm postures
Wrist	Wrist should be held in slight extension with fingers bent slightly Avoid wrist deviations beyond 20 degrees extension, 40 degrees flexion, 15 degrees radial deviation, and 25 degrees ulnar deviation. Extreme wrist excursions should not occupy >30% of operating time
Neck	Maintain neck flexion between 10 degrees and 30 degrees Avoid excessive twisting and limit axial rotation to <15 degrees In robotic surgery, forehead should rest only lightly on the headrest Avoid excessive "head forward" posture, as this increases degenerative changes in the cervical spine Avoid prolonged static positioning of the neck, particularly if in excessive flexion
Back/trunk	Stand close to patient to avoid bending and reaching Avoid pelvic girdle asymmetry by keeping feet hip-width apart with weight evenly distributed. Don't lock knees. Engage deep muscles of trunk and pelvis to maintain neutral position Perform postural "resets" and intraoperative stretching with squats Avoid prolonged static positioning, especially with twisted trunk position
Lower extremity	Avoid excessive knee flexion during robotic surgery. Place feet on ground in front of pedals at angle ≥90 degrees Dorsal flexion of the foot should be <25 degrees when controlling footswitch Consider supportive hose if prolonged standing is required
Instrument manipulation	Maintain working angle between laparoscopic instruments of 60 degrees. This will keep arms in comfortable, slightly inwardly rotated position Instrument intracorporeal-to-extracorporeal ratio should be >1
Post-surgery interventions	Perform neck, hamstring, and back stretches immediately after breaking scrub Incorporate stretching/flexibility modules into surgeon exercise programs (eg yoga, Pilates) and engage in regular massage Regular exercise is recommended and protective against surgeon injury

Adapted with permission from Catanzarite et al (2018).[66] Incorporates 2020 Copenhagen Recommendations.[59]

REFERENCES

1. Stylopoulos N and Rattner D: Robotics and ergonomics. Surg Clin North Am 2003; **83:** 1321.
2. Human Factors and Ergonomics Society website. Available at https://www.hfes.org/About-HFES/HFES-History. Accessed September 29, 2020.
3. Rivilis I, Van Eerd D, Cullen K et al: Effectiveness of participatory ergonomic interventions on health outcomes: a systematic review. Appl Ergon 2008; **39:** 342.
4. Hendrick HW: Determining the cost-benefits of ergonomics projects and factors that lead to their success. Appl Ergon 2003; **34:** 419.
5. Beevis D: Ergonomics—costs and benefits revisited. Appl Ergon 2003; **34:** 491.
6. Centers for Disease Control and Prevention: Workplace health promotion. Updated February 2020. Available at https://www.cdc.gov/workplacehealthpromotion/health-strategies/musculoskeletal-disorders/. Accessed September 29, 2020.
7. Bureau of Labor Statistics: Survey of occupational injuries and illnesses data. Updated September 2020. Available at https://www.bls.gov/iif/soii-data.htm#msd. Accessed September 29, 2020.
8. Kroemer KH: Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. Appl Ergon 1989; **20:** 274.
9. Pope MH, Goh KL and Magnusson ML: Spine ergonomics. Annu Rev Biomed Eng 2002; **4:** 49.
10. Kumar S: Trunk rotation: ergonomic and evolutionary perspective. Theor Issues Ergon Sci 2002; **3:** 235.
11. Franasiak J, Craven R, Mosaly P et al: Feasibility and acceptance of a robotic surgery ergonomic training program. JSLS 2014; **18:** e2014.
12. Szeto GP, Ho P, Ting AC et al: Work-related musculoskeletal symptoms in surgeons. J Occup Rehabil 2009; **19:** 175.
13. Franasiak J, Ko EM, Kidd J et al: Physical strain and urgent need for ergonomic training among gynecologic oncologists who perform minimally invasive surgery. Gynecol Oncol 2012; **126:** 437.
14. Davis WT, Fletcher SA and Guillamondegui OD: Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. J Surg Res 2014; **189:** 207.
15. Koneczny S and Matern U: Instruments for the evaluation of ergonomics in surgery. Minim Invasive Ther Allied Technol 2004; **13:** 167.
16. Epstein S, Sparer EH, Tran BN et al: Prevalence of work-related musculoskeletal disorders among surgeons and interventionalists: a systematic review and meta-analysis. JAMA Surg 2018; **153:** 1.
17. Park A, Lee G, Seagull FJ et al: Patients benefit while surgeons suffer: an impending epidemic. J Am Coll Surg 2010; **210:** 306.
18. Matern U and Koneczny S: Safety, hazards and ergonomics in the operating room. Surg Endosc 2007; **21:** 1965.
19. Capone AC, Parikh PM, Gatti ME et al: Occupational injury in plastic surgeons. Plast Reconstr Surg 2010; **125:** 1555.
20. Sivak-Callcott JA, Diaz SR, Ducatman AM et al: A survey study of occupational pain and injury in ophthalmic plastic surgeons. Ophthal Plast Reconstr Surg 2011; **27:** 28.
21. Babar-Craig H, Banfield G and Knight J: Prevalence of back and neck pain amongst ENT consultants: national survey. J Laryngol Otol 2003; **117:** 979.
22. Soueid A, Oudit D, Thiagarajah S et al: The pain of surgery: pain experienced by surgeons while operating. Int J Surg 2010; **8:** 118.
23. Auerbach JD, Weidner ZD, Milby AH et al: Musculoskeletal disorders among spine surgeons: results of a survey of the Scoliosis Research Society membership. Spine 2011; **36:** E1715.
24. Alleblas CCJ, de Man AM, van den Haak L et al: Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery. Ann Surg 2017; **266:** 905.
25. Hallbeck MS, Lowndes BR, Bingener J et al: The impact of intraoperative microbreaks with exercises on surgeons: a multi-center cohort study. Appl Ergon 2017; **60:** 334.
26. Omar M, Sultan MF, El Sherif E et al: Ergonomics and musculoskeletal symptoms in surgeons performing endoscopic procedures for benign prostatic hyperplasia. Ther Adv Urol 2020; **12:** 1.
27. Healy KA, Pak RW, Cleary RC et al: Hand problems among endourologists. J Endourol 2011; **25:** 1915.
28. Lloyd GL, Chung ASJ, Steinberg S et al: Is your career hurting you? The ergonomic consequences of surgery in 701 urologists worldwide. J Endourol 2019; **33:** 1037.
29. Tjiam IM, Goossens RH, Schout BM et al: Ergonomics in endourology and laparoscopy: an overview of musculoskeletal problems in urology. J Endourol 2014; **28:** 605.
30. Miller K, Benden M, Pickens A et al: Ergonomics principles associated with laparoscopic surgeon injury/illness. Hum Factors 2012; **54:** 1087.
31. Esposito C, El Ghoneimi A, Yamataka A et al: Work-related upper limb musculoskeletal disorders in paediatric laparoscopic surgery: a multicenter survey. J Pediatr Surg 2013; **48:** 1750.
32. Sari V, Nieboer TE, Vierhout ME et al: The operation room as a hostile environment for surgeons: physical complaints during and after laparoscopy. Minim Invasive Ther Allied Technol 2010; **19:** 105.
33. Wauben LS, van Veelen MA, Gossot D et al: Application of ergonomic guidelines during minimally invasive surgery: a questionnaire survey of 284 surgeons. Surg Endosc 2006; **20:** 1268.
34. Santos-Carreras L, Hagen M, Gassert R et al: Survey on surgical instrument handle design: ergonomics and acceptance. Surg Innov 2012; **19:** 50.
35. Plerhoples TA, Hernandez-Boussard T and Wren SM: The aching surgeon: a survey of physical discomfort and symptoms following open, laparoscopic, and robotic surgery. J Robot Surg 2012; **6:** 65.
36. Alleblas CCJ, Formanoy MA, Könemann R et al: Ergonomics in gynecologists' daily practice: a nationwide survey in The Netherlands. Work 2016; **55:** 841.
37. Dalager T, Søgaard K, Bech KT et al: Musculoskeletal pain among surgeons performing minimally invasive surgery: a systematic review. Surg Endosc 2017; **31:** 516.
38. Dolan LM and Martin DH: Backache in gynaecologists. Occup Med 2001; **51:** 433.
39. Choi SD and Brings K: Work-related musculoskeletal risks associated with nurses and nursing assistants handling

overweight and obese patients: a literature review. Work 2016; **53:** 439.
40. Gofrit ON, Mikahail AA, Zorn KC et al: Surgeons' perceptions and injuries during and after urologic laparoscopic surgery. Urology 2008; **71:** 404.
41. Berguer R, Rab GT, Abu-Ghaida H et al: A comparison of surgeons' posture during laparoscopic and open surgical procedures. Surg Endosc 1997; **11:** 139.
42. Kant IJ, DeJong LC, Van-Rijssen-Moll M et al: A survey of static and dynamic work postures of operating room staff. Int Arch Occup Environ Health 1992; **63:** 423.
43. Reyes D, Tang B and Cuschieri A: Minimal access surgery (MAS)-related surgeon morbidity syndromes. Surg Endosc 2006; **20:** 1.
44. Elhage O, Murphy D, Challacombe B et al: Ergonomics in minimally invasive surgery. Int J Clin Pract 2007; **61:** 186.
45. Nguyen NT, Ho HS, Smith WD et al: An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery. Am J Surg 2001; **182:** 720.
46. Gallagher AG, McClure N, McGuigan J et al: An ergonomic analysis of the fulcrum effect in the acquisition of endoscopic skills. Endoscopy 1998; **30:** 617.
47. Matern U: Ergonomic deficiencies in the operating room: examples from minimally invasive surgery. Work 2009; **33:** 165.
48. Matern U, Giebmeyer C, Bergmann R et al: Ergonomic aspects of four different types of laparoscopic instrument handles with respect to elbow angle: an electromyogram-based study. Surg Endosc 2002; **16:** 1528.
49. Berguer R, Chen J and Smith WD: A comparison of the physical effort required for laparoscopic and open surgical techniques. Arch Surg 2003; **138:** 967.
50. Berguer R, Gerber S, Kilpatrick G et al: An ergonomic comparison of in-line vs pistol-grip handle configuration in a laparoscopic grasper. Surg Endosc 1998; **12:** 805.
51. Neuhaus SJ and Watson DI: Laparoscopic surgeons' thumb—is it a training phenomenon? Minim Invasive Ther Allied Technol 1997; **6:** 31.
52. Horgan LF, O'Riordan DC and Doctor N: Neuropraxia following laparoscopic procedures: an occupational injury. Minim Invasive Ther Allied Technol 1997; **6:** 33.
53. Hemal AK, Srinivas M and Charles AR: Ergonomic problems associated with laparoscopy. J Endourol 2001; **15:** 499.
54. Cuschieri A: Whither minimal access surgery: tribulations and expectations. Am J Surg 1995; **169:** 9.
55. Hislop J, Tirosh O, McCormick J et al: Muscle activation during traditional laparoscopic surgery compared with robot-assisted laparoscopic surgery: a meta-analysis. Surg Endosc 2020; **34:** 31.
56. van't Hullenaar CDP, Hermans B and Broeders IAMJ: Ergonomic assessment of the da Vinci console in robot-assisted surgery. Innov Surg Sci 2017; **2:** 97.
57. Armijo PR, Huang CK, High R et al: Ergonomics of minimally invasive surgery: an analysis of muscle effort and fatigue in the operating room between laparoscopic and robotic surgery. Surg Endosc 2019; **33:** 2323.
58. González-Sánchez M, González-Poveda I, Mera-Velasco S et al: Comparison of fatigue accumulated during and after prolonged robotic and laparoscopic surgical methods: a cross-sectional study. Surg Endosc 2017; **31:** 1119.
59. Dalsgaard T, Jensen MD, Hartwell D et al: Robotic surgery is less physically demanding than laparoscopic surgery: paired cross sectional study. Ann Surg 2020; **271:** 106.
60. Albayrak A, Van Veelen MA, Prins JF et al: A newly designed ergonomic body support for surgeons. Surg Endosc Other Interv Tech 2007; **21:** 1835.
61. Steinhilber B, Hoffmann S, Karlovic K et al: Development of an arm support system to improve ergonomics in laparoscopic surgery: study design and provisional results. Surg Endosc 2015; **29:** 2851.
62. Kim FJ, Sehrt DE, Molina WR et al: Initial experience of a novel ergonomic surgical chair for laparoscopic pelvic surgery. Int Braz J Urol 2011; **37:** 455.
63. Engelmann C, Schneider M, Kirschbaum C et al: Effects of intraoperative breaks on mental and somatic operator fatigue: a randomized clinical trial. Surg Endosc 2011; **25:** 1245.
64. Dorion D and Darveau S: Do micropauses prevent surgeon's fatigue and loss of accuracy associated with prolonged surgery? An experimental prospective study. Ann Surg 2013; **257:** 256.
65. Giagio S, Volpe G, Pillastrini P et al: A preventive program for work-related musculoskeletal disorders among surgeons: outcomes of a randomized controlled clinical trial. Ann Surg 2019; **270:** 969.
66. Catanzarite T, Tan-Kim J, Whitcomb EL et al: Ergonomics in surgery: a review. Female Pelvic Med Reconstr Surg 2018; **24:** 1.

Study Questions Volume 40 Lesson 18

1. Four urologists share a urology practice that generates a variety of cases. All are healthy with a normal body mass index and all exercise regularly. The urologist at the greatest risk for a work-related musculoskeletal disorder is
   a. a 35-year-old woman who is 5'5" with a high, primarily robotic, surgical volume
   b. a 68-year-old man who is 6'1" with a low, exclusively endoscopic, surgical volume
   c. a 50-year-old woman who is 5'9" with a very high, very varied surgical volume
   d. a 45-year-old man who is 6'7" with a high, primarily robotic, surgical volume

2. You are in the middle of a surgical case with one of your residents, who has been holding the laparoscopic camera for 2 hours. In order to decrease ergonomic risk, you suggest the following:
   a. instruct your resident to increase shoulder abduction to 90 degrees in order to change the muscle groups that are being activated
   b. at a convenient time in the surgical flow, all members of the surgical team step away from the operating table for 2 minutes and take a stretch break
   c. instruct your resident to vary her posture by stepping off of her platform so that her elbows will be more bent (60–70 degrees) for a period of time
   d. no need to change anything, as long as the table height is appropriate and the resident is not noting any musculoskeletal pain

3. Consequences related to poor surgeon ergonomics and work-related musculoskeletal disorders (WMSDs) include
   a. costly workers' compensation claims related to surgeon injury
   b. settlements from surgeon litigation against institutions related to poor ergonomic training and equipment
   c. lost workdays, decreased productivity, and shortened careers
   d. increased utilization of traditional laparoscopic surgery instead of open procedures

4. You are beginning a laparoscopic surgical case and your assistant is 12 inches taller than you. Which of the following describes the most appropriate table height to prevent injury of both you and your assistant?
   a. 10–15 cm below your elbow height, to avoid having to stand on a platform
   b. in between your height and your assistant's height
   c. 10–15 cm below the tallest surgeon's elbow; you will need to stand on a platform
   d. at whichever height maintains your elbow flexion between 70 and 90 degrees

5. You are sitting down at the robotic console before an anticipated 5-hour case. In order to prevent musculoskeletal injury, you should
   a. position the console armrests in the most comfortable position first and then make other adjustments to the workstation
   b. just use the last surgeon's ergonomic settings so that you can get started with the case
   c. place as much pressure as possible on the forehead and headrest throughout the case to relieve strain to the neck and shoulders
   d. use a chair without wheels in order to prevent the chair from moving farther away from the console, which can lead to excessive back and arm flexion