Advances in Surgery 53 (2019) 209–220
ADVANCES IN SURGERY

Musculoskeletal Disorders in Minimally Invasive Surgery

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Keywords

• Ergonomics • Ergonomic challenges • Musculoskeletal disorders
• Musculoskeletal strain • Minimally invasive surgery • Laparoscopic surgery
• Robotic surgery • Endoscopic surgery

Key points

- Laparoscopic surgery has led to profound patient benefit since its introduction, but this has come at a great cost to the surgeon.
- Several studies have established that the association between musculoskeletal disorders and minimally invasive surgery are mainly attributed to ergonomic violations by the operative team.
- The solution to improving the ergonomic challenges among surgeons performing MIS will involve both high-tech and low-tech approaches.

BACKGROUND

The physical and mental demands of surgery have exacted their toll on surgeons over the centuries as they have performed their craft. Before the advent of general anesthesia, the hallmark of a successful surgeon, apart from expert knowledge and clinical judgment, was speed and accuracy in the conduct of operations. As the field has blossomed in the subsequent 170-odd years, the call upon surgeons to master an ever-expanding knowledge domain and the judgment that must keep pace has been joined by new physical demands of the profession. Surgeons have been able to develop longer more complex surgical

Disclosure statement: No conflicts of interest to declare. No financial support was received for this study.

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https://doi.org/10.1016/j.yasu.2019.04.020
0065-3411/19/

solutions to patients' disease and in the process have to assume prolonged, static, and often unhealthy postures in the operating room. As new imaging modalities, "energy sources," and aids to dissection/tissue manipulation entered routine use in the operating room, patient options, outcomes, and experiences improved tremendously. Not so the surgeon's experience during the course of bringing these advances in care to their patients.

Although our understanding of pathology, patient safety and outcomes, operative flow, and implementation of technology has almost arithmetically advanced, the essence of the surgeon-patient interface in the operating room (OR) has advanced not one whit. We still stand for extended periods at the patient's bedside (operating table) stretching, bending, and twisting ourselves while maintaining laser-like focus on the surgical task at hand. In this regard, the surgeon's workspace has changed little over the past several centuries.

Few examples better underscore this reality than the far more recent (25–30 years) advent of minimally invasive surgery (MIS). As Cushieri observed in MIS' infancy, "laparoscopic surgery represents a rare instance in surgical history where an advance has been so profound in patient benefit in so short a period of time." [1] These advantages enjoyed by the patient–which are profound in terms of decreased perioperative pain, enhanced return to function, and reduced surgical morbidity–come at great cost to the surgeon [2]. Surgeons' visualization of the target anatomy is no longer direct and is often at odds with their "working axes." We assume even more unhealthy and prolonged, static postures than in "open surgery." Furthermore, we contort ourselves to get our "end effectors" to anatomic destinations made immeasurably more difficult by the degrees of movement we have lost with laparoscopic instruments, all of which has given rise to the long overdue interest in and study of surgical ergonomics and surgeons' physical well-being.

As defined by the International Ergonomics Association, ergonomics comprehensively addresses the intellectual, physical, and organizational dimensions of human activity through assessment of safety, comfort, ease of use, productivity, performance, and aesthetics parameters [3]. Physical ergonomics regards how the body relates to its surrounding environment and accounts for resultant bodily consequences derived from posture, motion repetition, workplace design, material handling, and musculoskeletal strain. Mental ergonomics centers around the workings of cognitive operations, encompassing perceptual memory, sensory, and motor functions. Organizational ergonomics focuses on the influences of surroundings, workflow processes, and even employed guidelines.

In this article the authors review the most current studies of the risks of work-related injuries and symptoms faced by surgeons and some suggested strategies to mitigate the assaults on physical well-being that surgeons encounter by simply going to work every day.

LAPAROSCOPIC MINIMALLY INVASIVE SURGERY

As laparoscopy has become established as a predominant technical approach for a variety of surgeries across nearly all specialties, it has progressively replaced many open approaches [4,5].

Despite its many benefits for patients and the health care system as a whole, MIS has presented ergonomic challenges to surgeons, increasing their physical and psychological stress and compounding work-related injuries and burnout [6–10].

These challenges begin with the restricted degrees of freedom that constrain surgeons and for which they often compensate with suboptimal surgical postures and movement. They also have had to adjust to working from a two-dimensional image while working in a three-dimensional space [11,12]. Laparoscopic instrument designs have not meaningfully progressed over time with regard to facility of use [11,13]. Finally, the OR setup has failed to advance appropriately with time to optimize its interactions with surgeons and other staff.

A comparison of axial skeletal motions of surgeons during MIS versus open surgery show that although surgeons maintain more erect posture with respect to their head, neck, and axial spine during MIS, they are limited in motion [14]. In addition, their center of gravity favors a forward shift. Therefore, surgeons are more prone to short-term musculoskeletal strain with the risk of injuries over a prolonged period of MIS practice.

Electromyography (EMG) studies have been conducted to gain a more in-depth understanding of the ergonomic impact of MIS on specific muscles. One study analyzed the activation patterns of deltoid, trapezius, bicep, pronator teres, flexor carpi ulnaris, and extensor digitorum superficialis muscles of surgeons performing simulated laparoscopic tasks [15]. The emphasis was on the duration rather than the intensity of muscle activation. The results showed that muscle activation patterns were influenced most by the complexity of the task, followed by the design of instruments used and the physical adjustments of the operator to the task. Overall, proximal arm and shoulder muscle activations were greatest for all tasks, irrespective of complexity or instrument design, whereas forearm muscle activation became more prominent during complicated exercises.

The challenges of MIS extend beyond physical demands to also encumber surgeons with an increased mental workload. To quantify this mental workload, one study analyzed 28 surgeons performing simulation tasks using open versus video-endoscopic approaches. Measurements of mental stress were accomplished objectively with validated skin conductance and electrooculogram evaluations and subjectively with a survey query. There was congruence between subjective and objective measures showing that the endoscopic approach required greater concentration than the open approach. These findings are consistent with early experience that MIS demands greater focus and may amplify mental stress for surgeons [10].

Although investigations into ergonomic risk factors have been limited in the clinical domain of surgical practice, numerous studies have supported findings that show consistent ergonomic risk factor violations by nursing and surgeons in the OR during laparoscopic surgery [16–18]. Studies have also shown that simply performing MIS cases on a regular basis will subject practitioners to

its perils, irrespective of age, experience, gender, height, or handedness [4]. An online survey study of 317 MIS surgeons found high rates of fatigue/strain/injury with frequent laparoscopic surgery (87%). Most implicated poor design of instruments as the primary factor and identified postural adjustments as the most employed counterstrategy to their physical symptoms. Finally, the majority reported lack of education/awareness about proper ergonomic practices during MIS.

Other studies have supported these findings. A systematic review by Alleblas and colleagues [19] showed that the weighted average prevalence of physical complaints among laparoscopic surgeons was 74%. Another recent study showed a strong association between musculoskeletal disorders and MIS among a group of 14 pediatric surgeons [13]. These musculoskeletal disorders have involved the cervical spine, thoracic spine, upper limbs, lower limbs, and lumbar spine [20]. Their clinical manifestations include pain, muscle stiffness, numbness, and fatigue. These symptoms have a significant impact on surgical performance, indirectly affect patient safety, and may shorten surgeons' career longevity [13,19,21,22].

Overall, such studies are important in highlighting the current deficits in sound ergonomic practices among surgeons [23]. They also advocate task-specific positions, postures, and movements that promote excellent ergonomics and maximally counter fatigue and strain during MIS. The potential for these findings is significant in optimizing current surgeon/OR interactions. They also set the foundation for training future surgeons to acquire the proper ergonomic knowledge and skills to enhance their function and longevity while improving patient safety.

ROBOTIC MINIMALLY INVASIVE SURGERY

Robotic surgery has gained tremendous momentum across the world since its introduction in 2000. Nearly 450,000 cases were performed using robotic systems in 2012, a number 29% higher than the previous year [24]. This rate of growth has stemmed from novel MIS technologies affording 3-dimensional perception, enhanced degrees of freedom, motion scaling, and tremor reduction. Furthermore, this technology has allowed surgeons without prior MIS training to more easily adopt MIS techniques to deliver less-invasive care to their patients.

Studies have sought to determine whether robotic surgery improves on the ergonomic challenges posed by traditional laparoscopy. Several have shown improved ergonomics with reduced physical strain and mental stress for surgeons on robotic systems in comparison with those performing laparoscopy [25–28]. Some studies have used EMG and the National Aeronautics and Space Administration Task Load Index (NASA-TLX) to measure physical and mental workload, respectively [8,29]. Targeted anatomic regions for motion analysis with EMG included the:

- Elbow (biceps and triceps)
- Shoulders (deltoid and trapezius)

- Wrists (flexor carpi ulnaris and extensor digitorum)
- Thumbs (thenar compartment)
- Back (erector spinae)

A global performance score was also tabulated with respect to the partial or total task completion and performance errors. The results showed that robotic techniques were slower and less precise, but less stressful than laparoscopic techniques.

These studies found lesser mental and physical ergonomic demands of robotic surgery in comparison with laparoscopy. In addition, surgeons derived greater benefit from these ergonomic advantages by using better posture on the robot with lower shoulder position and reduced application of pressure to the armrest.

Nevertheless, the studies also indicated that while surgeons may be less negatively affected physically and mentally during robotic surgery, they derive the most benefit when they employ sound ergonomic principles during surgery [8,9]. Thus, even such sophisticated technology may lead to strain and injury if ergonomic considerations are not implemented during utilization.

Giberti and colleagues [20] evaluated a group of robotic surgeons who reported (41.2%) musculoskeletal disorders mostly in the cervical spine and upper limbs. These results were attributed to posture discomfort secondary to lack of an ergonomic seat and static position of the console operator, resulting in poor spine posture. A study by Zihni and colleagues [30] found no differences in activation of bilateral trapezius muscle groups between traditional laparoscopic surgery (TLS) and robotic-assisted laparoscopic surgery (RALS) using surface EMG measurement. These findings likely reflect the ergonomic strain placed on this muscle group secondary to cervical spine posture during TLS and RALS.

Thus, although the robotic console has been "purpose designed" to mitigate the ergonomic risk factor violations so rampant in MIS, whereby the patient-surgeon interface has seen no improvement over the years, the evidence to date suggests that the benefits to the surgeon are far from those anticipated. In fact, surgeons who spend regular operative time at the "robotic console" describe injury and symptom patterns consistent with those who regularly work at microscopes [31].

One would hope that as robotic surgery evolves and competition grows, surgeon console design will also evolve and improve ergonomically.

SURGICAL ENDOSCOPY

Surgeons commonly use endoscopic techniques via the upper or lower gastrointestinal tract to treat patients. When applicable, endoscopy that allows access to target anatomy and pathologic conditions by means of a natural orifice is considered the most minimally invasive of surgical techniques and offers patients the opportunity to avoid abdominal wall incisions altogether.

Flexible endoscopy still poses unique and major challenges to surgeons beyond laparoscopy [32]. The challenges revolve around the main tool, the flexible endoscope, with a comparatively condensed field of vision, diminished

lighting, less focal length, and reduced depth projection than the laparoscope. The endoscope's small diameter results in a restricted working domain, limiting the manipulation of operative instruments. Moreover, an accurate bimanual control of instruments is compromised secondary to the inability to triangulate when needed. Finally, lengthier procedures potentiate the physical and mental hazards of these techniques for those who may use them in their practice.

These travails have been echoed by surgeons and gastroenterologists who participate in high-volume endoscopic practices. Most report regular pain in their neck, upper back, shoulders, wrists, and thumbs [33,34]. Unfortunately, there remains a paucity of research to describe and characterize ergonomic risk factors associated with surgical endoscopy to improve equipment design and corresponding human factors and ergonomic issues.

INTERVENTIONS TO MITIGATE THE EFFECTS OF MUSCULOSKELETAL DISORDERS IN MINIMALLY INVASIVE SURGERY

Surgeon-directed efforts

Nearly 50% of doctors in the United States have experienced burnout [35]. Fortunately, in recent years there has been progress in shedding light on physician injuries, burnout, and the prospect of shortened career longevity [36–39]. The surgical culture of self-forfeit and sacrifice in the pursuit of patient care has come into question [40]. Today, physician and health care professional well-being programs are being established across health care facilities and institutions and are highly supported. These efforts are in recognition of not only a prevalent problem among health care professionals but also the critical importance of maintaining a precious workforce.

Targeted factors have included physician work hours, physical fitness, nutrition, and the use of mental coaching to address burnout [36,40,41]. Specific to surgeons, one evidence-based strategy has been the use of breaks during surgery. Its objective is to ensure that surgeons take a break from prolonged and static postures during MIS while at the same time allowing them to improve mental focus and physical function. The implementation of breaks to counter fatigue, reduce errors, and ensure safety has been a valuable strategy employed in many demanding and "high-stakes" work environments, including the air traffic control, translation, computer science, and even professional mountain climbing [42–44].

The impact of breaks during surgery has previously been investigated as a viable countermeasure to surgeon stress [45,46]. Engelmann and colleagues [46] randomized surgeons to perform surgery with and without taking 5-min breaks every half-hour during surgery. Their results showed that with regular breaks, there were gains in quality of technical execution while fatigue, strain, pain, hormone levels associated with stress (cortisol and testosterone), intraoperative "events," and error rates were reduced without adding significant operative time. Recently, a multicenter prospective study was conducted to determine the impact of intraoperative targeted stretching micro breaks

(TSMB) on surgeon pain, function, and focus. Surgeons and OR staff rated pain/fatigue, and physical and mental performance using validated scales during 2 operative days, one with and the other without intraoperative TSMB [47]. TSMB included standardized (90 s) guided TSMB at appropriate 30- to 40-min intervals throughout each case. Case type and duration were recorded as were surgeon pain data before and after each procedure and at the end of the surgical day. Sixty-eight participants (69% men, 31% women; mean 47 years) completed 193 "non-TSMB" and 146 "TSMB" procedures; 47% of surgeons were concerned that musculoskeletal pain may shorten their career. The most common approaches used to deal with musculoskeletal pain were changing position (60%), taking a break (34%), adjusting some aspect of the surgical field (29%), adjusting height (26%), and ignoring the pain (26%) (Fig. 1). TSMB improved surgeon postprocedural pain scores in the neck, lower back, shoulders, upper back, wrists/hands, knees, and ankles (Fig. 2). Operative duration did not differ ($P>.05$). Improved pain scores with TSMB were statistically equivalent ($P>.05$) for laparoscopic and open procedures. Surgeons perceived improvements in physical performance (57%) and mental focus (38%); 87% of respondents planned to continue TSMB beyond study completion. Overall, Park and colleagues [47] concluded intraoperative TSMB represents a practical and effective means to reduce surgeon pain, enhance performance, and increase mental focus without extending operative time. Other related studies have reported similar findings [48].

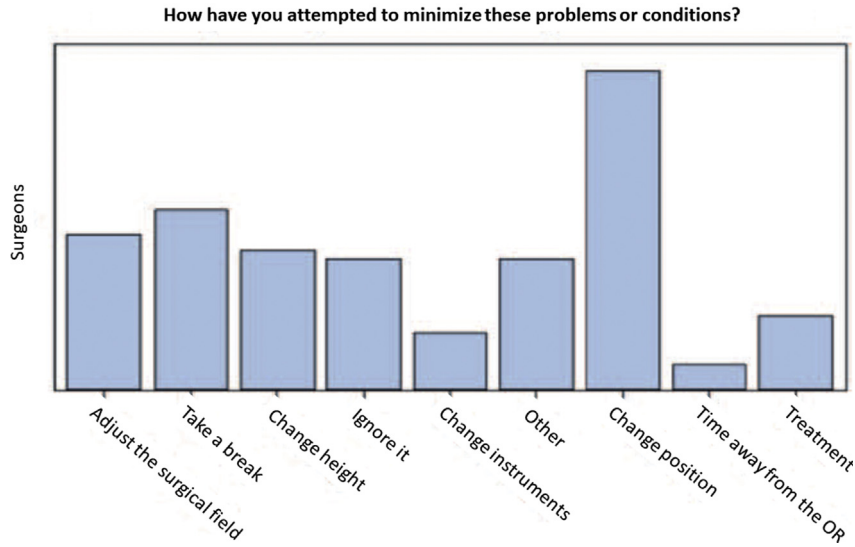

Fig. 1. Most popular counterstrategies by surgeons against pain and fatigue. (*From* Park A, Zahiri H, Hallbeck S, et al. Intraoperative "Micro Breaks" with targeted stretching enhance surgeon physical function and mental focus: a multicenter cohort study. Ann Surg 2017;265;340–6; with permission.)

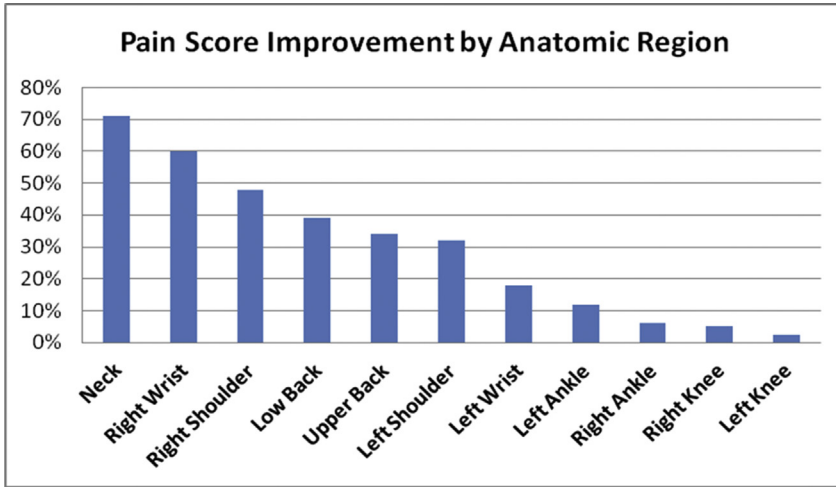

Fig. 2. Impact of TSMB on pain scores by anatomic site. (*From* Park A, Zahiri H, Hallbeck S, et al. Intraoperative "Micro Breaks" with targeted stretching enhance surgeon physical function and mental focus: a multicenter cohort study. Ann Surg 2017;265;340–6; with permission.)

Postural balance training is another tool that can help alleviate the ergonomic stress associated with laparoscopic and endoscopic procedures. Reddy and colleagues [49] evaluated the effect of improving posture and surgical ergonomics by teaching subjects completing laparoscopic skill assessment, a posture balance technique known as the Alexander technique. This technique improves postural balance and coordination while at the same time minimizing strain and maximizing comfort. Results from this study showed that subjects reported decreased discomfort, and posture assessment data revealed significant improvement in scores after adopting the Alexander technique. These findings demonstrate that postural training can aid in reducing ergonomic strain and stress during MIS.

Although these strategies are evidence-based and promising, their implementation, regular use, and effectiveness remain to be established among the surgical community. Without a concerted effort by health care leaders and, foremost, physicians, these strategies will continue largely as abstractions.

Operating room design

The need to optimize the OR environment to improve safety, efficiency, and workflow well predates the advent of MIS although its widespread adoption has overly magnified the inadequacies of the current state [50]. No longer are traditional ORs set up (geared toward open surgery) with bulky laparoscopic equipment crammed into a limited space adequate to accommodate the minimally invasive surgeon, patient, and OR staff. Unfortunately, these outdated designs, which can amplify risks of workflow disruptions, fatigue, strain, and injury to the entire operative team, continue to persist in most ORs in use

today. Multidisciplinary collaboration including physicians, registered nurses and associated health professional, biomedical engineers, and administration as well as the requisite funding need to be corralled to focus on significant new OR design. As new technologies constantly enter into use in the OR, both the surgeon-technology interface and the surgeon-patient interface need to be completely revisited, informed by our latest understanding of optimal ergonomic and human factor considerations in workspace design.

Laparoscopic instrument design

Another major challenge to overcome, geared toward the MIS industry, is updating the interaction of the surgeon with his or her instruments. Although laparoscopy has now been in existence for nearly 30 years, many of the instruments used by surgeons today have retained their original design without any innovation to accommodate MIS practitioners [51]. This is largely secondary to an inexplicable acceptance of the status quo and the lack of demand for better instruments by the surgical community! However, to ensure career longevity of surgeons it is essential to adopt a clinically driven approach whereby engineers work with surgeons to design the next generation of MIS instruments, centered around comfort and sound ergonomic principles. The time of a "one size fits all" surgical instrument handle is well past. At the least, they must now be designed and tailored to surgeon gloves/hands.

SUMMARY

A comprehensive approach to enhance ergonomics, prevent strain/injury, elevate performance, and ensure safety for surgeons will require more than isolated and disjointed surgeon-directed efforts. Rather, the environment surrounding and involving the surgeon and operating room staff must be ergonomically sophisticated to facilitate workflow while optimizing the patient and the entire OR team. As awareness has risen in recent years regarding the critical need to preserve our health care workforce, there is room for optimism that the culture of the health care industry will more rapidly change among all key stakeholders including doctors, nurses, executive leaders, and industry to demand protection, with the goal always of improving patients' outcomes and experiences.

References

[1] Cuschieri A. The spectrum of laparoscopic surgery. World J Surg 1992;16:1089–97.
[2] Park A, Lee G, Seagull FJ, et al. Patients benefit while surgeons suffer: an impending epidemic. J Am Coll Surg 2010;210(3):306–13.
[3] Int Ergon Assoc (IEA): what is ergonomics?. Available at: https://www.iea.cc/whats/index.html. Accessed October 10, 2018.
[4] Cuschieri A. Whither minimal access surgery: tribulations and expectations. Am J Surg 1995;169:9–19.
[5] Klein M, Anderson LPH, Alamili M, et al. Psychological and physical stress in surgeons operating in a standard or modern operating room. Surg Laparosc Endosc Percutan Tech 2010;20(4):237–42.

[6] Bohm B, Rotting N, Schwenk W, et al. A prospective randomized trial on heart rate variability of the surgical team during laparoscopic and conventional sigmoid resection. Arch Surg 2001;136:305–10.
[7] Vereczkei A, Feussner H, Negele T, et al. Ergonomic assessment of the static stress confronted by surgeons during laparoscopic cholecystectomy. Surg Endosc 2004;18: 1118–22.
[8] Berguer R, Smith W. An ergonomic comparison of robotic and laparoscopic technique: the influence of surgeon experience and task complexity. J Surg Res 2006;134:87–92.
[9] Matern U, Faist M, Kehl K, et al. Monitor position in laparoscopic surgery. Surg Endosc 2005;19:436–40.
[10] Berguer R, Smith WD, Chung YH. Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery. Surg Endosc 2001;15:1204–7.
[11] Seagull F. Disparities between industrial and surgical ergonomics. Work 2012;41: 4669–72.
[12] Kenngott H, Fischer L, Nickel F, et al. Status of robotic assistance—a less traumatic and more accurate minimally invasive surgery? Langenbecks Arch Surg 2012;397:333–41.
[13] Esposito C, Najmaldin A, Schier F, et al. Work-related upper limb musculoskeletal disorders in pediatric minimally invasive surgery: a multicentric survey comparing laparoscopic and SILS ergonomy. Pediatr Surg Int 2014;30:395–9.
[14] 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.
[15] Quick NE, Gillette JC, Shapiro R, et al. The effect of using laparoscopic instruments on muscle activation patterns during minimally invasive surgical training procedures. Surg Endosc 2003;17:462–5.
[16] Lee YH, Chiou WK. Ergonomic analysis of working posture in nursing personnel: example of modified Ovako Working Analysis System application. Res Nurs Health 1995;18: 67–75.
[17] Kant IJ, de Jong 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;63:423–8.
[18] Rademacher K, Pichler KV, Erbse S, et al. Using human factor analysis and VR simulation techniques for the optimization of the surgical worksystem. Stud Health Technol Inform 1996;29:532–41.
[19] Alleblas CC, de Man AM, van den Haak L, et al. Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery. Ann Surg 2017;266(6):905–20.
[20] Giberti C, Gallo F, Francini L, et al. Musculoskeletal disorders among robotic surgeons: a questionnaire analysis. Arch Ital Urol Androl 2014;86:96–8.
[21] Huysmans M, Hoozemans M. Fatigue effects on tracking performance and muscle activity. J Electromyogr Kinesiol 2008;18:410–9.
[22] Huysmans M, Hoozemans M. Position sense acuity of the upper extremity and tracking performance in subjects with non-specific neck and upper extremity pain and healthy controls. J Rehabil Med 2010;42:876–83.
[23] Lee G, Lee T, Dexter D, et al. Methodological infrastructure in surgical ergonomics: a review of tasks, models, and measurement systems. Surg Innov 2007;14(3):153–67.
[24] Lee GI, Lee MR, Clanton T, et al. Comparative assessment of physical and cognitive ergonomics associated with robotic and traditional laparoscopic surgeries. Surg Endosc 2014;28:456–65.
[25] Lee EC, Rafiq A, Merrell R, et al. Ergonomics and human factors in endoscopic surgery: a comparison of manual vs. telerobotic simulation systems. Surg Endosc 2005;19: 1064–70.
[26] Stefanidis D, Wang F, Korndorffer JR, et al. Robotic assistance improves intracorporeal suturing performance and safety in the operating room while decreasing operator workload. Surg Endosc 2010;24:377–82.

[27] Stefanidis D, Hope WW, Scott DJ. Robotic suturing on the FLS model possesses construct validity, is less physically demanding, and is favored by more surgeons compared with laparoscopy. Surg Endosc 2011;25(7):2141–6.
[28] Klein MI, Warm JS, Riley MA, et al. Mental workload and stress perceived by novice operators in the laparoscopic and robotic minimally invasive surgical interfaces. J Endourol 2012;26(8):1089–94.
[29] Marecik SJ, Prasad LM, Park JJ, et al. Evaluation of midlevel and upper-level residents performing their first robotic-sutured intestinal anastomosis. Am J Surg 2008;195(3):333–7.
[30] Zihni A, Ohu I, Cavallo J, et al. Ergonomic analysis of robot-assisted and traditional laparoscopic procedures. Surg Endosc 2014;28:3379–84.
[31] Park A. ''Physician heal thyself'' isn't working. Ann Surg 2017;266(6):921–2.
[32] Lee G, Sutton E, Clanton T, et al. Higher physical workload risks with NOTES versus laparoscopy: a quantitative ergonomic assessment. Surg Endosc 2011;25:1585–93.
[33] Shergill AK, McQuaid KR, Rempel D. Ergonomics and GI endoscopy. Gastrointest Endosc 2009;70:145–53.
[34] Liberman AS, Shrier I, Gordon PH. Injuries sustained by colorectal surgeons performing colonoscopy. Surg Endosc 2005;19:1606–9.
[35] West CP. Physician well-being: expanding the triple aim. J Gen Intern Med 2016;31(5):458–9.
[36] Hamidi MS, Boqqild MK, Cheung AM. Running on empty: a review of nutrition and physicians' well-being. Postgrad Med J 2016;92(1090):478–81.
[37] Rothenberger DA. Physician burnout and well-being: a systematic review and framework for action. Dis Colon Rectum 2017;60(6):567–76.
[38] Arora M, Asha S, Chinnappa J, et al. Review article: burnout in emergency medicine physicians. Emerg Med Australas 2013;25(6):491–5.
[39] Arora M, Diwan AD, Harris IA. Burnout in orthopaedic surgeons: a review. ANZ J Surg 2013;83(7–8):512–5.
[40] Schneider S, Kingsolver K, Rosdahl J. Physician coaching to enhance well-being: a qualitative analysis of a pilot intervention. Explore (NY) 2014;10960:372–9.
[41] Blum AB, Shea S, Czeisler CA, et al. Implementing the 2009 Institute of Medicine recommendations on resident physician work hours, supervision and safety. Nat Sci Sleep 2011;3:47–85.
[42] Farmer E, Brownson A. Review of workload measurement, analysis and interpretation methods (CARE-Integra-RES-130-02-WP2). Technical report prepared for the European Organisation for the Safety of Air Navigation. Brussels, Belgium: Eurocontrol.
[43] McLean L, Tingley M, Scott RN, et al. Computer terminal work and the benefit of microbreaks. Appl Ergon 2001;32(3):225–37.
[44] Caceres-Munoz VS, Magallances-Meneses A, Torres-Coronel D, et al. Effect of rest pauses combined with information leaflets on the decrease in musculoskeletal pain in administrative workers. Rev Peru Med Exp Salud Publica 2017;34(4):611–8.
[45] Mukhopadhyay BK. Strategic rest break in laparoscopic surgery: a need. World J Laparosc Surg 2012;5(2):85–8.
[46] Englemann C, Schneider M, Kirschbaum C, et al. Effects of intraoperative breaks on mental and somatic operator fatigue: a randomized clinical trial. Surg Endosc 2011;25:1245–50.
[47] Park AE, Zahiri HR, Hallbeck MS, et al. Intraoperative ''Micro Breaks'' with targeted stretching enhance surgeon physical function and mental focus: a multicenter cohort study. Ann Surg 2017;265(2):340–6.
[48] Schrempf M, Anthuber M. Intraoperative microbreaks reduce pain and improve concentration. Chirurg 2017;88(3):256.

[49] Reddy P, Reddy T, Roig-Francoli J, et al. The impact of the Alexander technique on improving posture and surgical ergonomics during minimally invasive surgery: pilot study. J Urol 2011;186:1658–62.
[50] Herron DM, Gagner M, Kenyon TL, et al. The minimally invasive surgical suite enters the 21st century. Surg Endosc 2001;15:415–22.
[51] Sancibrian R, Gutierrez-Diez MC, Torre-Ferrero C, et al. Design and evaluation of a new ergonomic handle for instruments in minimally invasive surgery. J Surg Res 2014;188:88–99.