REVIEW ARTICLE

Review of Ergonomics in Minimally Invasive Surgery

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Abstract

Musculoskeletal occupational injury is prevalent within the surgical community. This is a multi-factorial issue but is contributed to by physical posture, environmental hazards, and administrative deficiency. There is growing awareness of this issue, with several behavioral, educational, and administrative techniques being employed. The literature on this topic is, however, sporadic and difficult to access by healthcare practitioners.

The aim of this review was to evaluate the literature on the current interventions used to minimize musculoskeletal occupational injury in surgeons and interventionalists. This review will focus on engineering interventions, administrative interventions, and personal protective equipment.

Keywords: Ergonomics, Laparoscopic, Minimal invasive surgery.

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Introduction

Surgeons generally concentrate on procedural improvement and strive toward perfection. One of the crucial factors which will enhance the abilities and ensure smooth conduct of the surgical procedures is ergonomics. Even though ergonomics is learned during training, it is commonly ignored or not strictly adhered to. This might impede and rather increase the learning curve.

The synchronicity of the surgeon and his workplace, and the operating room is one of the important elements that surely influences the whole experience of the surgeon. The topic of ergonomics has not been of priority among researchers. Sporadic research has been trying to establish some recommendations but has not been quite successful in ensuring the strict adaptation of ergonomic principles.

Surgeons with their routine of performing complex and technically demanding surgeries are highly prone to occupational hazards.[1] Surgeons during the procedures tend to be positioned in very awkward or non-neutral positions and often for long durations which will lead to musculoskeletal problems. Specialty surgeons of plastic operate wearing coupes and they have to bend sharply at the neck region which causes cervical region strain;[2] the other good example is the orthopedics who wear heavy lead aprons which cause muscular fatigue.[3,4] A heavy lead apron can even injure the vertebral disc prolapse.[5–8]

The evolution of open surgery into minimal access surgery has hugely benefitted the patients but unfortunately made the surgeon's life more demanding. The technical challenge of minimal access surgery pushes the risk of musculoskeletal injuries.[5,9–26] The surgeon's freedom of movement and odd positions for long hours increase the risk by many folds.

The ergonomic peril has been addressed in the recent decade. Many randomized controlled trials (RCTs) have shown the risk among surgeons as high as 68% in form of pain.[27] Surgeons performing minimal access surgery face this occupational injury, and to an extent of 87% of surgeons reporting it as per the study by Park et al.,[28] the injury to the back and the incidence of disc prolapse has been reported around 15%.[29] The areas involved were commonly the back in which ~50% the upper body is involved including the shoulders, and arms were average around 45%.

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The work injury not just affected the professional life at the operating but surprising impacted the social life also. A study revealed that 41% of the participants agreed that this pain due to the work injury negatively affected their relationships. The other major concern was sleep which was disturbed and possibly reduced cognitive abilities subsequently leading to unwarranted errors during the procedures.[13] As a result of the multi-facet influence of occupational hazard, the long-term career would be clearly affected and even end in burnout.

The necessity for intervention in form of medications was noted in 29%, and most of the others felt that the pain increased only during performing the procedure.[27] Few (31%) even had to undergo surgery due to the pain.

Another major impact was seen in form of sick leave. A survey showed as many as 26% took sick leave and 40% had to make some mechanical adjustment in the operating room.[30] All these significant effects show the glaring need for attention.

These occupational injuries have a wide range of consequences, ranging from physical pains to psychological bearing. A survey revealed that many 47% of the surgeons feared that this injury will surely reduce their career span.[31] This concern is not just an assumption, but rather a survey among the ophthalmic plastic surgeons reported to have stopped operating due to either pain or fear of spinal injury.[32]

The wellbeing of the healthcare workers and here the surgeon is of utmost importance. This will undoubtedly matter in patient care. A total of 30% of surgeons admitted that their symptoms

influenced either directly or indirectly even in decision making for the patients and even affected the surgical planning.

The next big concern is the interest of the future medical students on whether this will influence the career option to choose to be a surgeon. A study showed that many students did not prefer surgery as their subject of choice due to the lingering fear of musculoskeletal injuries.[33]

A solution to handle this situation is the immediate need for ergonomic corrections. This can be conveniently divided into the following three groups:

1. Engineering controls
2. Administrative controls
3. Personal protective equipment

Engineering controls are mainly focused on physical structural changes in the operating room, such as manipulating the table height, and equipment changes, such as changes in instrument handles design, using 3D/high definition (HD) monitor, proper monitor position, and exact camera position.

Administrative controls are mainly the workforce or human factors. These include maintaining a neutral body posture such as altering wrist posture during surgery, reducing neck rotation during surgery and balancing the load on dominant or non-dominant shoulder.

Personal protective equipment are the tools individual surgeons might use, such as customized surgical exosuits or body support equipment.

These three categories of control intertwine and each plays a role in potential improvement. In this study, we aim to perform a review of the literature on Engineering interventions, administrative interventions and personal protective equipment used to reduce musculoskeletal occupational injury in surgeons. This is because these interventions are internationally available and require a relatively small amount of resources to incorporate into practice.

The term administrative controls mean the external control or regulator which here is the surgeon's hand movement holding the instruments.

The surgeon may use an additional supportive measure such as the exosuit to enhance his ability which becomes the personal gear or the personal protective equipment. These are additionally used to reduce any health or occupational injuries. Few of such equipment are available across the world and with such easy access, the utilization in everyday practice is highly likely.

Methods

Information Sources and Search

Literature was searched in free access search engines such as the Google Scholar, PubMed, and journal websites such as Springer. The technical terms were used to filter the right and relevant articles. The duplicate articles were excluded. The abstracts along with the title was used as the key search factor.

Inclusion Criteria

- Studies on ergonomics of the operative room.
- Studies involving ergonomics of the operating surgeons and the instrumentation.
- Studies on innovation in a surgical instrument for reducing the ergonomic errors.

Exclusion Criteria

- Studies on ergonomic research in labs other than the operating room.
- Non-surgeon participants
- Studies on custom-made equipment.

Intervention(s)

- Engineering intervention is the modification that makes structural changes in the operating room such as the operating table and laparoscopic instruments such as changes in instrument handle design, using 3D/HD monitor, proper monitor position, and exact camera position.
- The term administrative controls mean the external control or regulator which here is the surgeon's hand movement holding the instruments, neck rotation during surgery, and load on the dominant or non-dominant shoulder, shoulder position during surgery, neck stiffness, back stiffness, and back pain during surgery, musculoskeletal disorders during surgery, and need of ergonomic training programs.

The surgeon may use an additional supportive measure such as the exosuit to enhance his ability which becomes the personal gear or the personal protective equipment.

Results

With the filtering using the criteria, only 12 studies qualified. A total of six of them studied on specialized instruments.[12,34–43] (Flowchart 1). Of these, six studies investigated the use of engineering interventions.[22,34–37] Five studies investigated the use of administrative interventions.[39–44] One study investigated the use of personal protective equipment.[12] Table 1 provides a description of the engineering intervention studies; Table 2 provides a description of the administrative intervention studies; Table 3 provides a description of the study of intervention by personal protective equipment.

Participants

The participants of the studies were from various branches of surgery and specialties such as general, urology, gynecology, surgeons.[12,22,34–43]

Outcome Measures and Results

Since there is methodological diversity and can instill bias the outcome along with the results will be separately discussed.

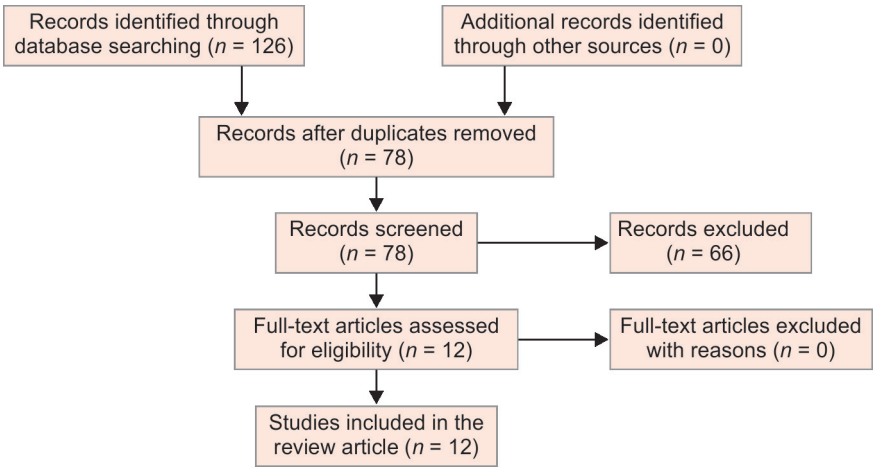
Engineering Interventions

Matern et al. arrived at a conclusion with the electromyography (EMG) data that the monitor positioned at the level of the eye is recommended. Based on the individual surgeon's choice and skill, it is definitely an advantage with two monitors situated, one at position A for complex tasks or procedures and the lowest muscular fatigue at the position B. Either way, the position of the monitor lateral to the surgeon is not recommended.[34]

Gallagher et al. concluded that the camera has to be steady and any movement which is unwarranted would result in complications or risk safety.[35]

Manasnayakorn et al. opined that for the hand-assisted laparoscopic procedures the operating table height should be 5 cm above the elbow or the surface of the hand instruments used.[22]

Flowchart 1: Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram for the selection of studies



Sancibrian et al. arrived at the conclusion that the specifically designed significantly improved the efficiency of the surgeon in completing the asks and were better than the conventional RH instruments.[36]

Tung et al. concluded that the pistol grip was found to be far better than the regular grip and it was noted to have reduced the task–peg transfer and cutting time. The results also suggested reduced pain but with the data, and the possibility of having bias of subjective variability it was not possible to arrive at a definitive conclusion on the effect of tool design.[37]

Harada et al. concluded that even though the 3D/HD monitor might provide an advantage over the 2D/4K monitor for the operating expert surgeon in most cases, the 2D/4K monitors might score over these in narrow or finer working areas over the 3D/HD with their high-resolution images.[38]

Administrative Interventions

Stomberg et al. concluded that the incidence of musculoskeletal injuries and problems is higher in surgeons performing minimal access surgeries. This is due to the long hours of static posture or non-neutral positions of the body during the procedures. The general surgeons and gynecologists were found prone to such injuries.[39]

Miller et al. concluded that occupational injury in the form of musculoskeletal problems is common among surgeons. These could be due to non-ergonomic body postures. They added that with better awareness, knowledge, and following the right rubrics these can be reduced.[40]

Tjiam et al. concluded that urologists particularly endourologists experience a high rate of musculoskeletal injuries. The insufficient knowledge among the urologist about ergonomics was highlighted by this study. They recommended the introduction of ergonomic principles in the surgical curriculum in the early phase of the career to gather knowledge. Hoping that this move will reduce occupational injuries.[41]

Aitchison et al. identified four crucial areas which are putting the surgeons at risk of having injuries. (1) The asymmetrical movement between the dominant shoulder and the non-dominant one; (2) The constant awkward positions of the neck; (3) The repetitive in and outward instrument movement through the ports; (4) The long duration of odd positions.[42]

Bartnicka et al. concluded that there exists an inverse relationship between the benefit to the patient and surgeon wrist strain.[43]

Personal Protective Equipment

Liu et al. concluded that the operative procedure interference would not happen with the exosuit, which rather will be a minimal gear device that can be worn by the surgeon. This can drastically decrease fatigue and pain.[12]

Discussion

Ergonomics is an interplay between the human here the surgeon and the environment which in this case is the operative room and the surgical instruments. Surgical devices and instruments which are designed following ergonomic principles will hugely benefit the surgeon and ensure the smooth conduct of the intended procedure. This field of ergonomics is still in the infancy stage as compared to other sectors such as aerospace, car design, etc. This study attempted to study the overall role of the application of ergonomic principles in the operative room. This is much-needed study as the application is comparatively minimal among the surgical fraternity.

Engineering Interventions

The most important aspect of any surgical intervention is the minimal complication rate and faster recovery rate. This can be achieved with precision which demands some strain on the surgeon musculoskeletal system. The relation between the duration of the procedure and the strain appears to be directly proportional to each other.

None of the surgeons felt the side position of the monitor would be ideal; subject preferred the monitor at the side position.[34]

The study conducted by Gallagher et al. provided results that in study 1, the outcome among the resident's performance came down ($p = 0.00001$) due to the movement of the camera. Further, the error rate was significantly high ($p = 0.00001$). In study 2, the task of intracorporeal knotting was prolonged and it was due to the camera movement again ($p = 0.00001$), hence it is advisable that the unwarranted movement of the camera should be avoided and steadiness would reduce the errors.[35]

Table 1: Engineering interventions studies

S. No.	Title of abstract	First author	Year	Conclusion
1.	Monitor position in laparoscopic surgery	Matern et al.[34]	2005	Regarding EMG data, the monitor positioned frontal at eye level is preferable. Reflecting on personal preferences of subjects and task performance, it should be of advantage to place two monitors in front of the surgeon: one in position A for lowest neck strain and the other in position B for difficult tasks with optimal task performance. The monitor position at the side is not advisable
2.	An ergonomic analysis of the effects of camera rotation on laparoscopic performance	Gallagher et al.[35]	2009	Unintentional camera rotation during surgery should be avoided to eliminate one potential source of errors
3.	Ergonomic assessment of optimum operating table height for hand-assisted laparoscopic surgery	Manasnayakorn et al.[22]	2009	The optimum table height for hand-assisted laparoscopic surgery allows the working surface of the extracorporal instrument handle to be at or 5 cm above the elbow level
4.	Design and evaluation of a new ergonomic handle for instruments in minimally invasive surgery	Sancibrian et al.[36]	2014	The new ergonomic handle not only provides important ergonomic advantages but also improves efficiency when completing tasks. Compared with ring handle (RH) instruments, the new prototype reduced the high-pressure areas and the extreme motions of the wrist
5.	The effect of ergonomic laparoscopic tool handle design on performance and efficiency	Tung et al.[37]	2015	There was a significant preference for as well as lower pain experienced during the use of the pistol grip tool as seen from the survey feedback. Both evaluation tasks (cutting and peg transfer) were also completed significantly faster with the pistol grip tool. Finally, due to the high degree of variability in the error data, it was not possible to draw any meaningful conclusions about the effect of tool design on the number or degree of errors made
6.	The effect on surgical skills of expert surgeons using 3D/HD and 2D/4K resolution monitors in laparoscopic phantom tasks	Harada et al.[38]	2018	Compared to a 2D/HD monitor, a 3D/HD monitor improved the laparoscopic surgical technique of expert surgeons more than a 2D/4K monitor. However, the advantage of 2D/4K high-resolution images may be comparable to a 3D/HD monitor especially in narrow spaces

EMG, electromyography

Table 2: Administrative interventions studies

S. No.	Title of abstract	First author	Year	Conclusion
1.	Work-related musculoskeletal disorders when performing laparoscopic surgery	Stomberg et al.[39]	2010	This study revealed musculoskeletal disorders in a majority of laparoscopists. The laparoscopic technique often requires static and tiring work positions, sometimes extreme, which can explain musculoskeletal disorders among general surgeons and gynecologist
2.	Ergonomics principles associated with laparoscopic surgeon injury/illness	Miller et al.[40]	2012	Results suggest that awareness, knowledge, and utilization of ergonomic principles could protect surgeons against symptoms that lead to occupational injury
3.	Ergonomics in endourology and laparoscopy: An overview of musculoskeletal problems in urology	Tjiam et al.[41]	2014	We recommend integration of ergonomics in hands-on training programs early in the residency curriculum to gain knowledge and awareness and hopefully to offer possibilities to prevent these complaints in the future
4.	The ergonomics of laparoscopic surgery: A quantitative study of the time and motion of laparoscopic surgeons in live surgical environments	Aitchison et al.[42]	2016	The following four primary areas have been identified where surgeons are consistently demonstrating movements that increase their risk of harm: (1) Extended periods of neck rotation (2) Asymmetrical loading between the dominant and non-dominant shoulders (3) Power morcellation and frequent insertions/removals of laparoscopic instruments resulting in repetitions of the most extreme shoulder positions (4) A negative correlation between height and percentage of time spent in more extreme positions
5.	An ergonomics study on wrist posture when using laparoscopic tools in four techniques in minimally invasive surgery	Bartnicka et al.[43]	2018	The outcomes proved that the surgical technique which is best for the patient imposes the greatest strain on the surgeon's wrist

Table 3: Interventions by personal protective equipment studies

S. No.	*Title of abstract*	*First author*	*Year*	*Conclusion*
1.	Solving the surgeon ergonomic crisis with surgical exosuit	Liu et al.[12]	2018	The progressive arm support exosuit can be a minimally intrusive device that laparoscopic surgeons wear to reduce pain and fatigue of surgery without significantly interfering with operative skills or manual dexterity

The influence of ergonomics on the performance of the surgeon is quite evident. This particularly is more in the surgeons performing minimally invasive surgeries which reduce the freedom of movement and the instruments push the surgeons toward an unfavorable and uncomfortable position.[44]

This very important factor can be understood from a study by Manasnayakorn et al.[22] The experiment assessed three different positions of the elbow above the table. First 10 cm revealed a long time to do tasks such as the intracorporeal suturing. Even the second position, that is, 15 cm also showed a negative impact on the outcome. This laid heavy strain, particularly on the deltoid, trapezius, and the paraspinal muscles. and lastly, the strain was observed on the flexor muscles of the arm in the final position of 5 cm.[22]

Sancibrian et al. evaluated the ergonomics of newer and innovative handpiece of laparoscopic instruments. This was compared with that of the conventional ring handle. and the results were encouraging for the newly designed device. Majority of the participants (64%) liked the new device as it reduced pain and fatigue. the key to the new instrument was less need for the hyperflexion at the wrist.[36]

Tung et al. studied the comparison between the pistol grip and the pinch grip. Volunteers who participated preferred the pistol grip which is ergonomic friendly whereas the other group suffered from pain and discomfort., further the duration in completing the tasks was shorter with the pistol grip ($p < 0.05$). They did not find any correlation between the tool and the type of error[37] and the study by Harada et al. noted the advantage the 2D/4K monitors have over the 3D/HD in visualizing target organs in very narrow spaces due to the high resolution.[38]

Administrative Interventions

Not many studies have been conducted on the role of administrative interventions. In the study by Stomberg et al.,[39] they recorded that most of the surgeons who conduct these minimally invasive surgeries suffered from some form of musculoskeletal problems. Discomfort if not pain was found to be very high among them. At least around 70% of surgeons admitted to behaving some injuries. joint stiffness was quite a common issue apart from headaches and problems with vision.

Gender played a significant role with lady surgeons expressing more discomforts ($p < 0.01$). The time was a vital factor in determining the possibility of developing the injuries. The longer the duration of surgery more injuries were noted ($p < 0.01$).

The non-neutral position when held for a long time contributes to these injuries. It is not uncommon among surgeons and gynecologists who have these long-duration procedures.[39]

Miller et al. found that those who gave the option of undecided in the questionnaire were more likely be suffering from this occupational hazard as compared to those who were well aware of the ergonomic principles. A few of the common symptoms were stiffness in neck and back.[40]

Tjiam et al.[41] had a total of 285 responses. Among these, almost 86% of urologist had suffered from some form of musculoskeletal issues in the last 1 year, and the majority were work-related common sites of these were in the neck and shoulder.

About one-third of the participating urologist accepted to have poor or minimal knowledge about the ergonomic principles and the influence of these on the outcome. Half of them were quite agreeable to the special training on ergonomics to be included along with the training in their urology skills. This led to the recommendation of including the module in the surgical curriculum. This will be the first step in preventing the health hazard to come down in the future.[41]

The study by Aitchison et al. found that BMI had no influence on ergonomics and so was the experience which did not contribute to this.[42]

The study by Bartnicka et al. arrived at a conclusion that task specification was important including the pattern of movement and dynamics.[43]

Personal Protective Equipment

In the study conducted by Liu et al., they gave attention to the influence of any additional devices which can be used to enhance ergonomics or provide support to the body posture, but at the same time not hamper the movement or dexterity of the surgeon. A total of 20 surgeons were part of this study which used an exosuit and assessed its influence of it. They found that these suits do not interfere with the performance of the surgeon ($p = 0.15–0.84$). They did a comparative study between a group that used and a control group that did not use the exosuit. The task was holding the camera for 15 minutes. It was found that the group without the suit experienced more pain and discomfort as compared to the ones who were wearing the suit (3.11 vs 5.88; $p = 0.019$). Most of the surgeons (~85%), who used the suit were more comfortable at the end of the day.[12]

It is becoming clearer about the necessity of a structured training program in the curriculum. A small study showed that more than half of the participants (53.2%; $n = 5,125$) accepted about the lack of formal training and were keen on getting the training.[45]

It was observed that many of the surgeons who are facing the work-related musculoskeletal problems were the ones who lacked the training programs in ergonomics. A total of 21% sought for right suggestions and modifications to reduce the non-neutral position themselves and follow the right postures during the procedure, and many (69.9%) after practicing ergonomics observed improvement in their health and were free of pain or discomfort.

However, it appears that we are far from achieving a complete application of the right ergonomics in the operating table. The lack of time for the surgeon sort of pushes the importance of ergonomic settings to be made in the operating room. More research is now begun in this highly vital area.

Regulations on the design of instruments do not usually consider ergonomics and might be contributing the non-ergonomic instruments in to the hands of the surgeons, more regulations are needed to end this practice.[46] A recent meta-analysis showed something glaring, that is, the lack of knowledge among

the surgeons and 55–90% of the surgeons had not got any formal training in ergonomics, even though some tried to adopt the recommendations.[27]

Conclusion

Ergonomics appears to be a neglected facet, with 68% experiencing some or the other form of work-related musculoskeletal problems. This review attempted to highlight the importance of these good practices. Further, this study highly recommend a structured formal training program for all surgeons and even includes it in the curriculum. Engineering interventions, administrative interventions, and personal protective equipment are the three most important parts. Improvement must be ensured in these three groups to get the optimal operating environment. The field of ergonomics must be given priority and relevant attention. Ergonomic guidelines should be periodically evaluated and corrected. Further work is suggested to refine the ergonomic practices.

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