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Optimising ergonomics in minimally invasive gynaecological surgery: a comprehensive review and practice recommendations

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ABSTRACT

Background: Modern minimally invasive gynaecological surgery greatly contributes to women's health; however, it can be physically demanding for surgeons. A plethora of available data shows that the optimisation of ergonomics in the operating room (OR) is crucial for the health and efficiency of surgeons.

Objectives: To provide an overview of the importance of ergonomics and clinically useful, concise recommendations.

Methods: A literature review with critical analysis of available data.

Main Outcome Measures: Impact of ergonomics on the prevalence of musculoskeletal disorders (MSDs), fatigue levels, efficiency and subjective comfort among surgeons.

Results: Evidence suggests that MSDs are highly prevalent among minimally invasive gynaecological surgeons and that several ergonomic interventions can greatly reduce muscle strain and improve clinical practice, with the most important being the planning of brief intraoperative breaks, the selection of proper laparoscopic instruments and the positioning of the operating table and monitor at the correct height. The adoption of robotic surgery can also improve surgical ergonomics. Clinical practice recommendations for ergonomic improvement in gynaecological laparoscopy based on the existing evidence are provided.

Conclusions: Surgeons must be aware of the optimal ergonomic settings in the OR and impose measures to reduce risks and achieve a comfortable environment.

What is New? A comprehensive, praxis-oriented review with exact ergonomic advice for minimally invasive gynaecological surgeons.

Keywords: Ergonomics, laparoscopic, musculoskeletal disorders, operative setting, robotic, surgeon health, surgical efficiency

Introduction

Minimally invasive gynaecological surgery is currently used for the diagnosis and treatment of various disorders. Despite its benefits for the patients, this approach can be physically demanding and can lead to musculoskeletal injuries among surgeons, nurses, and other healthcare workers.[1] Therefore, interventions that reduce these risks are needed. Ergonomics is the science of designing and arranging the workplace, equipment, and tasks to fit the capabilities and limitations of the human body. In the context of laparoscopy, ergonomics can play a

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crucial role in reducing the physical strain and improving the performance of surgical teams.[2] This is crucial for surgeons' career longevity and quality of life, because performing laparoscopic surgery has been shown to cause fatigue, strain and injury irrespective of age, experience and handedness.[3]

This review aims to explore the current knowledge on ergonomics for gynaecological laparoscopy. We investigate the hypothesis that specific ergonomic interventions can reduce the prevalence of musculoskeletal disorders (MSDs) among surgeons and improve their overall surgical performance. Moreover, we summarise concise recommendations regarding the optimal ergonomic settings based on available data.

Methods

Search Strategy and Study Eligibility

The systematic search was conducted in the ScienceDirect, PubMed/Medline, and Google Scholar databases without any restriction on the publication date. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines were used.[4] The protocol for this review was registered at PROSPERO (CRD42023452153). The search focused on studies that evaluated ergonomic or surgeon strain parameters during laparoscopic surgery. The following keywords were used: (laparoscopic OR robotic) AND (ergonomics OR ergonomic) AND (gynecological OR gynecologic), (laparoscopic OR robotic) AND musculoskeletal AND (gynecological OR gynecologic). The search was performed in October and November 2023.

Inclusion criteria were surgeons as subjects (primary operators and assistants). Exclusion criteria were work-related MSDs among hospital staff outside the operating room (OR). The main outcomes to be considered were the avoidance of musculoskeletal injury of surgeons, the reduction in fatigue and the improved efficiency and operative time. Randomised controlled trials and prospective or retrospective randomised cohort studies were included. Because of the narrative character of this review and the need to suggest optimal ergonomic recommendations and ideas, review articles and society guideline websites were also included. Only full-text articles were included. Inaccessible articles and articles in languages other than English were excluded.

Data Extraction

Articles from the initial database search were searched for duplicates. Two hundred thirty-four articles were screened by titles and abstracts for irrelevant articles. After assessing content according to the inclusion/exclusion criteria, articles were scanned by the authors for relevant information and supplemented with online scientific committee sources and two book chapters. Finally, 86 sources were included. Study design, baseline characteristics, modality of surgery (laparoscopic or robotic) and exact setting, OR table height, OR setup and surgeon positioning were extracted for comparison from full-text articles. No missing data was defined.

Strategy For Data Synthesis

Narrative synthesis assessing the quality of studies and bias.

Evidence

Research Tools: Research tools that have been utilised to study surgical ergonomics can be broadly categorised into subjective and objective instruments.[5] Subjective tools include validated questionnaire scales that study discomfort in specific body regions or subjective assessment of the mental and physical workload, performance and frustration.[6] Objective tools include electromyography measurements of muscle activity and fatigue[7] and kinematic tracking through video[8] or special sensors, like accelerometers.[9] With the above research tools, valuable information about the ergonomic risk factors, as well as the common musculoskeletal problems in surgeons, could be obtained.

Ergonomic Risk Factors in Gynaecological Laparoscopy: Laparoscopy requires surgeons and staff to maintain prolonged static postures, awkward body positions, and repetitive movements, which can result in MSDs such as neck pain, back pain, shoulder pain, and hand-arm vibration syndrome. A systematic review showed that the average prevalence of physical complaints among laparoscopic surgeons was 74% and that the prevalence of MSDs is higher in minimally invasive surgeons than in any other occupational group.[10] Several task-related factors affect the risk for MSDs in laparoscopy, such as instrument design, equipment placement, and surgical technique, as well as individual factors, such as age, gender, and physical fitness.

Gynaecological surgeons are especially prone to MSDs because of the additional musculoskeletal strain due to the parallel exposure to vaginal surgery.[11] During vaginal surgery, the assistant stands holding retractors beside the primary surgeon with excessive trunk rotation and prolonged asymmetrical upper extremity strain. A study comparing the frequency and duration of strenuous body postures between assistant and primary surgeons demonstrated that while both experience high durations of trunk lateral bending and neck and shoulder deviations, the assistant surgeons spent a greater percentage of working time in trunk flexion compared to the primary surgeon.[12] In operative laparoscopy, data suggest that surgical assistants face significant ergonomic stress, just as operating surgeons do.[13]

Many instruments, common in advanced minimally invasive gynaecological surgery, i.e. endoscopic needle-drivers, demonstrate reduced degrees of freedom, enhanced fulcrum effect, and magnification of minimal tremor.[14] Moreover, conventional laparoscopic instruments create an inefficient transfer of force and an uneven lever effect towards the fingers of the surgeon, which can result in pain, fatigue, and neuropraxia.[15]

Minimally invasive surgery involves more internal shoulder rotation, elbow flexion and wrist supination than open surgery, and larger ranges of motion are required of the upper extremities due to the instrument length.[16] A quantitative study of laparoscopic surgeons' movements in live surgical environment utilizing video analyses demonstrated that surgeons spent a median of 98 % (range 77-100%) of surgical time with their neck rotated at >21° (range 0°-52°) with shoulder flexion at 45°-90° for 35% vs. 0% (P<0.001) and elbow flexion at >120° for 31 vs. 0 % (P<0.001) of total surgical time.[17] The non-dominant arm was subjected to more extreme positions for significantly longer periods of time compared to the dominant arm. Power morcellation was associated with the additional strain of multiple instrument insertions and removals, however, this technique is used less in recent years in many parts of the world following considerations of cancer cell dissemination. Short heighted surgeons, in particular (reference height 170 cm), spend more time in these extreme joint and posture positions.[18]

Hand size significantly affects the ergonomics of laparoscopic instruments and can lead to an increased risk of MSDs.[19] Available data suggest that smaller hand dimensions and glove size, as well as female sex, are associated with a higher probability of MSDs.[14] Indeed, various endoscopic surgery instruments, i.e. staplers, are designed for a minimum hand size. A study furthermore reported that the most appropriate instrument size for surgeons with a given hand size is not the same for male and female individuals, but needs to be established separately for each sex, ideally by developing smart instruments whose usability is not affected by the gender of the user.[20] Unfortunately evidence suggests that this also applies to the current disposable laparoscopic devices that do not fit the needs of female laparoscopic surgeons.[21] Indeed, women are still more likely to describe the laparoscopic instruments as uncomfortable to handle and seek more frequent treatment for MSDs. In a recent study, women were found to have 5.37 times the odds of physical complaints attributed to the use of laparoscopic instruments (odds ratio: 5.37; 95% confidence interval: 2.56-11.25).[22] Because of the rapidly increasing number of women entering the field of operative gynaecology, these limitations are likely to gain importance in the future.

Common Musculoskeletal Disorders in Surgeons

The overall risk of work-related musculoskeletal symptoms in surgeons has been calculated at up to 90%.[23,24] The highest levels have been recorded among surgeons who perform complex minimally invasive gynaecological surgery,[25] with 52% of the individuals reporting persistent pain in an online survey. The neck, shoulders, and wrists are the most investigated areas for MSDs, followed by the ankle, knee, back, upper back, elbow, lower back, thumbs, mid-back, fingers, and hips.[26] Interestingly, the prevalence of MSDs seems to increase with the number of years of laparoscopic practice.[27]

Neck and Shoulder Pain

Neck and shoulder pain are common complaints among surgeons, with studies reporting prevalence rates ranging from 56% to 85%.[28] The repetitive use of upper extremities during surgery, the prolonged static postures, and the awkward positioning are all risk factors for developing neck and shoulder pain. The ergonomic impact of laparoscopy on surgeons has been studied at the level of specific muscles through electromyograms. The activation patterns of deltoid, trapezius, biceps, pronator teres, flexor carpi ulnaris, and extensor digitorum superficialis muscles have been analysed during simulated laparoscopic tasks. Proximal arm and shoulder muscles were impacted the most.[29]

Low Back Pain

Low back pain is another common musculoskeletal complaint among surgeons. A descriptive, cross-sectional study showed prevalence rates of up to 68%.[28] The prolonged standing or sitting in awkward positions during surgery, as well as the repetitive nature of surgical tasks, can contribute to the development of low back pain. Currently, limited evidence shows that exercise programs can reduce the prevalence of pain, however, most surgeons experience ongoing symptoms.[30]

Carpal Tunnel Syndrome

Carpal tunnel syndrome is a common hand and wrist injury among surgeons, with prevalence rates up to 34%. Repetitive hand movements, awkward hand positions, and forceful gripping of instruments are all risk factors for developing carpal tunnel syndrome. An online questionnaire study found that, while ergonomic interventions, such as adjustable instrument handles and padded gloves, could reduce the incidence of carpal tunnel syndrome, most surgeons were unaware of the possible ergonomic solutions and didn't consider adopting any appropriate preventive measures.[31]

Lower Extremities

Posture-related MSDs of the lower extremities, especially in the knee and ankle/foot regions, appear to be common among surgeons, with reported prevalence up to 65%.[32] Increased prevalence of varicose veins has been well-documented[33] and standing places significant pressure on the joints of the hips, knees, ankles and feet and without significant movement, the lubrication of the synovial joints is diminished, causing increased wear. These MSDs are of particular importance for the surgeons' quality of life, because they appear to have a maximum impact on their leisure activities.[1]

Interestingly, the MSDs experienced by surgeons seem to have implications on clinical practice, with up to 30% of surgeons reporting that they consider their symptoms as a factor in choosing the operative approach.[34]

Ergonomic Interventions for Gynaecological Laparoscopy

Ergonomic interventions across a diverse range of industries in modern working environments have been shown to decrease lost workdays and sick leave,[35] and to improve efficiency and employee satisfaction.[36] In general terms, ergonomic improvements in the occupational setting have been proven to be cost-efficient[37] Despite this evidence, limited ergonomic interventions have been implemented for surgeons until recently.[38]

Ergonomic interventions can help reduce the physical strain and MSDs associated with laparoscopy. Fortunately, there are available effective ergonomic guidelines which are proven to reduce the risk of MSDs.[39] Some of the commonly used ergonomic interventions in laparoscopy include the following:

Intraoperative Breaks: During training and clinical practice, surgeons often develop a high level of concentration on patient outcomes, which frequently leads to neglecting their own needs during operations. Therefore, even microbreaks of some seconds are uncommon in laparoscopic surgery. However, current data suggest that work breaks during complex laparoscopic surgery can reduce psychological stress and preserve performance without prolongation of the operation time compared with the traditional work scheme. A randomised clinical trial found that regular intraoperative breaks did not prolong the operation (176 vs. 180 min, $P>0.05$) and the surgeon's cortisol levels, as an indicator of stress during the operation, were reduced by 22 ± 10.3% ($P<0.05$).[40] Another prospective study concluded that muscular fatigue and loss of accuracy can almost completely be prevented by microbreaks: In an experiment with surgeons under increasing fatigue, manual accuracy, measured by mistakes made when following a predetermined path on a board and discomfort, measured by a visual analogue scale, were vastly eliminated by microbreaks.[41] In a multi-centre cohort study, discomfort in the shoulders of surgeons incorporating microbreaks was significantly reduced, while distractions and flow impact were minimal, with the majority of surgeons reporting that they would alter their clinical routine after the exposure to the study.[42]

Regarding surgeon body positioning during prolonged laparoscopy, avoiding prolonged extreme body and trunk positions seems to be crucial. Laparoscopic surgery allows for more head/neck positioning flexibility in comparison with open surgery because the monitors can be adjusted. Preferably, the neck should have a small degree of flexion from 15° to 25°, while the shoulders should be below 20° of abduction and 40° of internal rotation.[43] The elbows should have a flexion of 90°-120°, and the wrists should not exceed 15° of deviation or flexion in any direction.[44] The positioning of foot pedals should be placed in an ergonomically favourable position, directly to the side of the working foot and should enable the knees to be soft and unlocked, feet hip-width apart, and body weight equally distributed. Surgeons should limit foot dorsiflexion to below 25° over the pedal and, if possible, utilise shoes without extreme external width, which can minimise the risk of accidental pedal and energy engagement.

The Alexander technique, a process of psychophysical re-education of the body to improve postural balance and coordination initially described in open surgery, has also been adopted in operative laparoscopy with positive impact in ergonomics and, interestingly, also in laparoscopic skills assessment scales.[45] The optimal body positioning for gynaecological laparoscopy is shown in Figure 1.

The design of laparoscopic instruments and equipment can significantly impact the physical strain and the performance of surgeons and staff. Ergonomically designed instruments, such as those with angled handles, adjustable tension and ergonomic grips, can reduce the strain on the hand, wrist, and forearm muscles and improve the precision and control of surgical movements. Especially those that minimise wrist flexion and rotation, and ulnar deviation should be selected.[46] Equipment placement, such as the position of monitors, can also impact the posture and neck flexion of surgeons and staff. Additionally, the selected instruments should be appropriate for the surgeon's anthropometry and the exact intended task.[47] Laparoscopic suturing and knotting constitute a special ergonomic challenge, where the camera angle and the distance between the working trocars play a crucial role. The ideal geometry has been proposed in an in vitro model study. An isosceles triangle between the instruments, with an angle between 25° and 45° and an angle of <55° between the instruments and the horizontal, facilitates faster and more relaxed suturing.[48]

In recent years, handheld robotic laparoscopic instruments have been developed. While lacking the motorised arm support of the full-scale robotic platforms, these instruments aim to improve ergonomics in complex laparoscopic tasks like intracorporeal suturing.[49] Indeed, the design of these instruments enables up to 360° rotation and some degree of three-dimensional articulation and can be combined with several end effectors, possibly reducing prolonged awkward wrist positions for the surgeon.[50] Furthermore, proximal interphalangeal flexion of the thumb and the metacarpophalangeal and proximal interphalangeal flexion of the index finger seem to be reduced with handheld robotic assistance.[51]

Structured Training and Education: Proper training and education can improve the ergonomic awareness and skills of surgical teams and reduce the risk of MSDs. Training programs can include instruction on proper body mechanics, postures, and movements, as well as exercises to improve strength, flexibility, and endurance. A recent electromyography study found that trained individuals had lower muscle activation (P<0.05), muscle workload (P<0.05) and better bimanual dexterity than the trainee surgeons at baseline.[52]

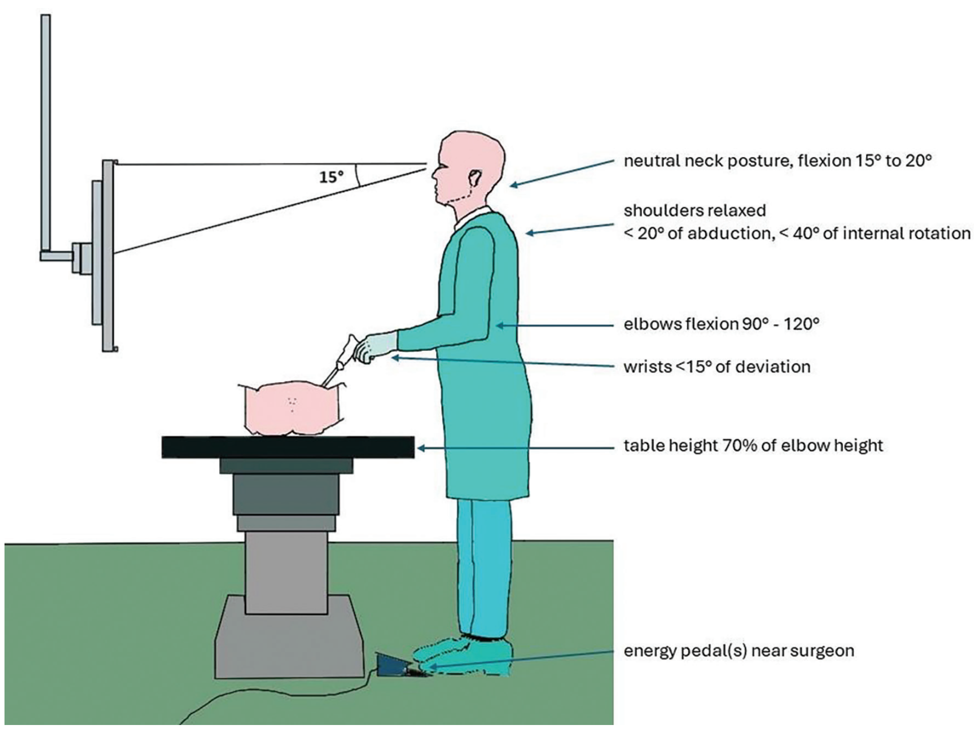

Figure 1. Recommended posture and setting for gynaecological laparoscopy.

Environmental Modifications: Environmental modifications, such as adjustable lighting, temperature control and noise reduction, can improve the comfort and well-being of surgical teams and reduce the risk of MSDs. Modern laparoscopic ORs are equipped with multiple ceiling-suspended flat-screen monitors that facilitate versatile positioning around the operative field. The exact adjustment of each monitor in location, height, and inclination within a comfort distance and in the direct field of vision of each surgeon can reduce eyestrain and improve posture during prolonged operations.[44,53] The correct placement of the endoscopic image, as a sole intervention, has been shown to decrease the operative time by 10%, even for procedures that do not require complex suturing skills.[54] In the case of intracorporeal knot tying, a randomised controlled trial could demonstrate that both knot quality ($P<0.01$) and execution times ($P<0.01$) could be improved with the monitor straight in front of the operator at the level of the hands.[55] This finding contrasts with the common perception of the OR staff that the monitor should be at the level of the eyes or higher. Indeed, the optimal height zone appears to lie 15 degrees lower than sight level. The direct ergonomic impact of monitor positioning could be highlighted in a study utilising electromyography and ultrasonic position transmitters, which compared several monitor angles (display at 0°, 17.5°, and -35°) and clearly proved that muscle effort increased with viewing angle.[56]

Recent data suggest that proper workload management, such as task rotation, can reduce the physical strain and fatigue associated with laparoscopy. Task rotation can help distribute the physical demands across different body regions and reduce the physical strain.[57,58] In particular, surgeons and assistants switching sides of the table to balance the strain on the upper extremities has been proposed.[59]

Proper holding and manipulation of laparoscopic instruments are essential for successful laparoscopic surgery. Incorrect handling of the instruments can lead to tissue damage, prolong the surgery, and increase the risk of complications. The surgeon should hold the laparoscopic instrument in a relaxed and comfortable grip, using the thumb and index finger. The grip should be firm enough to control the instrument, but not so tight as to cause hand fatigue. The other fingers should be relaxed and not holding the instrument, as this can cause unnecessary tension and strain.[60] Using the dominant hand can improve the surgeon's dexterity and control over the instrument, reducing the risk of tissue damage and other complications. The surgeon should use their wrist and fingers to manipulate the laparoscopic instrument, rather than their shoulder or elbow. This can reduce the risk of shoulder and neck strain, as well as improve the surgeon's control over the instrument (fine positioning).[61]

The height of the operating table is an important factor to consider during laparoscopic surgery, as it can affect the surgeon's posture and increase the risk of musculoskeletal injuries. The optimal height of the operating table for laparoscopic surgery depends on several factors, including the surgeon's height, the type of procedure, and the size of the patient. Generally, the operating table height should be adjusted to ensure that the surgeon's elbows are at a comfortable and neutral position when holding laparoscopic instruments.[62] OR tables were designed for open operations and are too high for many surgeons performing laparoscopic surgery. The ergonomically optimal operating surface height for laparoscopic surgery has been previously assessed in a study performed in a pelvic-trainer setting, with the strain being measured with questionnaires and electromyography.[44] The optimal patient height during a laparoscopic procedure is suggested to be 0.7× to 0.8× surgeon elbow height, which allows joints to stay in their neutral position for more than 90% of the operation duration. This proposed formula results in heights with an average of only 77 cm, whereas for open surgery, the equivalent lies at about 122 cm. Usual operating tables have a range of 73-122 cm, which, given the extra height of the supine patient, would be too high for 95% of minimally invasive surgeons.[63] While a stool is available in every setting, this solution is not sufficient in all scenarios. Energy devices require the surgeon's pedals and balance of the surgeon, and with the parallel use of various pedals, can be demanding.

Special Equipment which Aims Solely to Improve Surgeons' Comfort is Available: Special ergonomic chairs with adjustable heights should be readilyavailable.[64] For prolonged operations, a randomised controlled trial has shown that robot-assisted camera holders can decrease the strain of the assistants.[65] The OR staff should ensure that the lights are adequately dimmed to ensure glare reduction and display contrast enhancement, while simultaneously allowing safe movements throughout the room.[66] Cables and tubes usually clutter the floor of the OR, creating physical hazards for operators and staff. Organising the cables at the beginning of surgery, as well as ceiling-mounted boom systems for cables outside of the direct proximity of surgeons, can enhance safety and reduce physical obstacles, hence improving ergonomics. Whereas it has been proven that surgeons can effectively block out noise, it is preferable to reduce noise in the OR to improve communication within the team, especially in emergencies.[67] Additionally, when planning ergonomics for complex gynaecological laparoscopy, it is important to organise both patient and equipment placement to facilitate conversion to laparotomy or patient resuscitation.

Ergonomic Factors of Robotic Surgery

Robotic surgery is a minimally invasive surgical technique that uses robotic systems to perform surgical procedures. It offers several ergonomic benefits over traditional open or laparoscopic surgery, which can improve surgical outcomes and reduce the risk of injuries for the surgical team. At the same time, robotic surgery creates new challenges and special issues that must be addressed.

The customizability of the surgeon's console can greatly improve surgeon ergonomics, resulting in less overall back, shoulder, neck, and wrist pain.[68] A recent prospective cohort study suggested adjusting the console to achieve the most neutral neck angle and lowering the viewfinder until visibility into the device is uninhibited while sitting up straight, usually at a viewing angle of approximately 15° below the horizontal.[69] Back flexion should be less than 15°, while neck flexion should not exceed 25°, which is a low-risk posture as assessed in MSDs risk assessment validated tools.[8] Robotic surgeons should be instructed that the head should rest lightly on the console headrest to avoid forehead pain and increased neck strain.[70] Forearms should rest on the console armrests to cater for a more relaxed soldier position and free flexion of the elbows.[71] It is important to frequently utilise the clutches that enable the free adjustment of the controls to keep the hands in the neutral position ("sweet spot" in the robotic surgery argot).[46] The recommended surgeon positioning for ergonomic improvement in robotic surgery is shown in Figure 2.

Reduced Physical Strain and Fatigue

Robotic surgery systems allow for more ergonomic positioning for the surgical team, which can reduce physical strain and fatigue. The surgeon sits at a console that is typically located away from the patient, allowing for a more comfortable, neutral posture. This can reduce the risk of musculoskeletal injuries, such as neck and back pain, which are common in traditional laparoscopic surgery. A survey of physical discomfort and symptoms following open, laparoscopic, and robotic surgery found that surgeons experienced significantly less physical strain and fatigue during robotic-assisted surgery compared to laparoscopic surgery.[72] Additionally, the forearms can rest on the armrest of the console and are hereby protected from gravity strain.[73]

Improved Visualization

Robotic surgery systems offer improved visualisation of the operative field, which can reduce the risk of errors and complications. The systems provide high-definition 3D imaging, which allows for better depth perception and visualisation of anatomical structures. This can reduce the need for awkward head positions or repeated instrument exchanges and can improve ergonomics for the surgical team. Several studies found that through the tremor-free 3D immersive optics, robotic surgery provided better visualisation of the surgical field compared to laparoscopic surgery.[74,75]

More Precise Instrument Control

Robotic surgery systems offer more precise instrument control, which can reduce the risk of errors and complications. Robotic instruments are designed to mimic the movements of the surgeon's hand and wrist, allowing for greater dexterity and control.[76] This can reduce the need for excessive force or repetitive motions, which can reduce the risk of injuries caused by hand and wrist strain. Currently, the use and demand for robotic medical and surgical platforms are increasing, and new technologies are continuously being developed with promising possible ergonomic advantages for surgeons.[77]

Importantly, MSDs persist in robotic surgery, albeit at a lower rate than in laparoscopic surgery.[78] In the field of gynaecology, a large survey reported 54% of participating gynaecologic robotic surgeons experiencing physical symptoms or discomfort.[79] Discomfort in the fingers and neck was the most reported problem. In a online questionnaire survey robotic surgery was found to be more likely than either open or laparoscopic surgery to lead to eye or finger symptoms, and more likely than open surgery (but not laparoscopic surgery) to lead to thumb symptoms.[72] Additionally, prolonged sitting without lumbar support creates greater intradiscal strain than standing.[80] A further ergonomic limitation of robotic surgeons affects bedside assistant surgeons, who are exposed to unnatural positions under the threat of sudden motion of the robotic arms. In one study, 73% of bedside assistants reported discomfort, stressful positioning of the upper extremities, trunk, neck, and shoulder.[81] A further study reported that robotic assistance is associated with worse neck posture, but lower overall and mental workload compared to the console surgeon.[82] Importantly, a questionnaire survey reported that only a small percentage of robotic surgeons (17%) received ergonomic training prior to practice.[38]

In conclusion, robotic surgery offers several ergonomic benefits over traditional open or laparoscopic surgery. It allows for more ergonomic positioning for the surgical team, improved visualisation of the operative field, more precise instrument control, and reduced smoke and noise exposure. These benefits can improve surgical outcomes and reduce the risk of injuries for the surgical team. However, more studies are needed to explore the long-term effects of robotic surgery on the ergonomics and health of the surgical team.

Based on the mentioned evidence, we propose an ergonomics checklist for the minimally invasive gynaecological surgeon (Table 1) to safeguard his/her own well-being and the well-being of the surgical team.

Discussion

Even though, when confronted with questionnaires, surgeons answer that ergonomics should be part of minimally invasive gynaecological surgery training, less than 20% of surgeons report ergonomic training during residency and fellowship, and less than two-thirds of surgeons with one-time training in ergonomics incorporate those principles into practice.[83,84]

Work-related MSDs have an enormous impact on work absenteeism and decreased productivity.[85] Moreover, they have a negative impact on the healthcare professionals quality of life.[86] Entering the OR, gynaecological minimally invasive surgeons follow guidelines and standard operating procedures to ensure patient safety. Unfortunately, surgeon safety has received little attention in the demanding and developing field of minimally invasive surgery, creating an environment in which "patients benefit while surgeons suffer".[84] Hence, we propose that proper ergonomics are integrated in the preoperative team-time-out checklists of minimally invasive gynaecological surgery. Additionally, and in this context, "we should stand by our surgical assistants"[87] and ensure that all our colleagues, including, in particular, the second assistant, frequently seated between the legs do have proper ergonomic conditions and unhindered vision of the monitors. In robotic surgery, care should

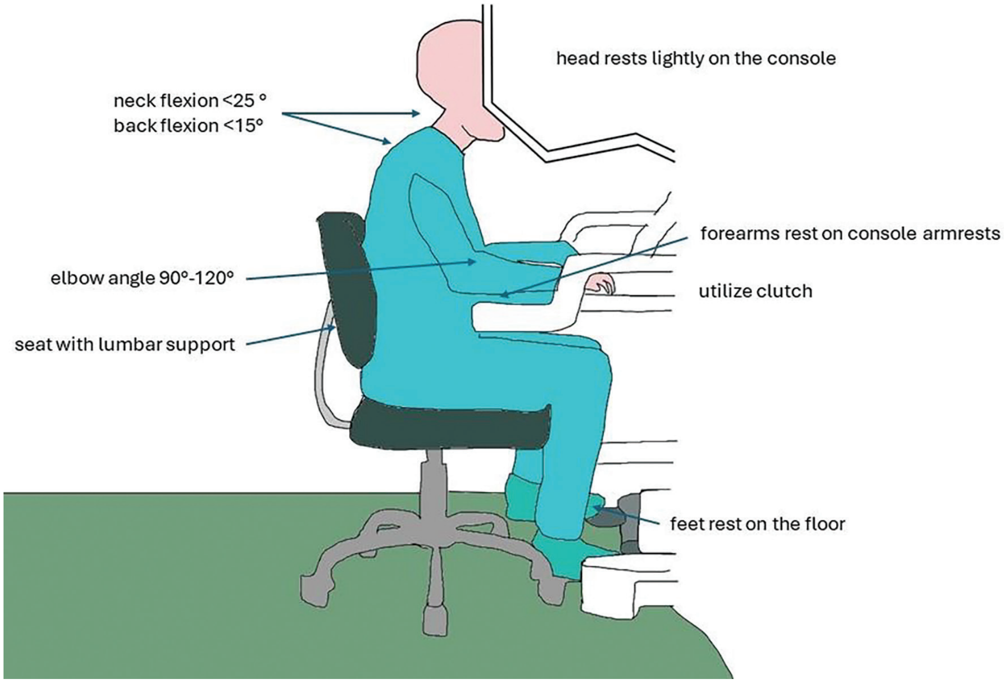

Figure 2. Recommended posture for gynaecological robotic surgery.

Table 1. Proposed ergonomic checklist for minimally invasive gynaecological surgery.
Patient positioning, room settings
Patient positioning, i.e. arms should not interfere with the surgeon
The operating table must be adjusted to optimise the surgeon's posture, and avoid using stools
The monitor should be slightly below eye level, at the level of hands, to maintain a neutral neck posture
Instrumentation
Ergonomically designed and familiar instruments, which use trigger locks and ratchets, should be used to minimise sustained gripping
Surgeon positioning
Keep your back straight, shoulders relaxed, and feet flat on the floor
The wrists should be straight and not bent, with the hands and fingers relaxed. when available, use the instruments' rotation
Organizational
Surgeons should take regular, preferably preplanned breaks during long procedures to rest and stretch their muscles
If possible, switch to robotics for complex operations
In robotics, follow the exact console instructions for ergonomic adjustment
Communicate ergonomic difficulties, encourage assistants to speak out

be taken that the assistants are not threatened by the sudden movements of the robotic arms.

The American College of Surgeons Division of Education established a Surgical Ergonomics Committee to systematically address the ergonomic challenges experienced by surgeons and improve their ergonomic well-being.[66] A well-documented recommendations bulletin with detailed general and technique-specific recommendations has been issued in 2022.[88] Worldwide, many hands-on laparoscopic training courses focus on ergonomic improvements and teach the proper OR settings.

Rehearsal of surgical techniques through simulation training enables tutors to demonstrate the appropriate posture and surgical technique as well as the correct utilisation of surgical instruments, hence significantly contributing to ergonomic improvements.[89] In this context, it is possible to assess ergonomics from video recordings during simulation training using automated movement assessment tools. The results can enable trainees to improve their posture and skills at the very early stages of their surgical career.[90]

Switching to robotic-assisted laparoscopy can be seen as an ergonomic upgrade in most scenarios. Additionally, current robotic surgical systems facilitate the central collection of real-time surgical data. These data can be analysed and, given the ability to integrate multiple sources simultaneously and the advances in artificial intelligence, console ergonomics are likely to be further improved to fit most surgeons.[91] However, the availability of this infrastructure is still scarce due to cost.

This report focuses on the importance of improved ergonomics for surgeons' well-being. However, it has been shown that many incidents which affect patient safety can be attributed to poor ergonomics of healthcare personnel.[92] Even though there is high-quality data that demonstrates that workplace ergonomics improve outcomes, especially in healthcare, the direct effect of improvements in laparoscopy ergonomics on complication rates is yet to be measured.

In modern healthcare, financial cost arises as an important factor in decisions and planning. Providing the training, settings and infrastructure for optimal ergonomics in the high-tech setting of modern ORs will, inevitably, commit financial resources. Therefore, the decision makers acceptance of ergonomic improvements in minimally invasive gynaecological surgery will increase if this improvement proves to be cost-effective. Indeed, ergonomic interventions have proven themselves cost-effective through predictive cost-benefit analyses in most industries and can be seen as a safety intervention.[93] Hopefully, future regulatory changes in occupational safety will facilitate these improvements internationally.

Strengths and Strengths and Limitations of the Study

There are obvious limitations in the applicability of recommendations on optimal ergonomics in minimally invasive gynaecological surgery: Exceptions should be made to fit the anthropometric differences between surgeons or special situations such as pregnancy or obesity, as well as the target anatomy of the patient.[94] Additionally, some interventions will not be possible in some institutions due to financial reasons.

Conclusion

This review has demonstrated the importance of ergonomics in minimally invasive gynaecological surgery and that general recommendations regarding ergonomic interventions are possible. Along with our commitment to the well-being of the patients, it is our responsibility as physicians to ensure optimal conditions for our working environment.

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