Peer Review File

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Reviewer A

This study describes the ergonomics of robotic systems via narrative review of the literature.

This is a narrative rather than systematic review. Narrative reviews introduce bias and can incompletely or inadequately represent the available evidence in the literature. Narrative reviews are informal and lack rigorous reporting methodology. This manuscript provides a general overview of the ergonomic advantages of robotic surgery. It is well written, but provides only a rudimentary synopsis of topics that are likely to be more thoroughly reported elsewhere in the literature. It may be useful in providing a straightforward introduction to robotic surgery for non-robotic surgeons or non-surgeons to reference. As a robotic surgeon reading the manuscript, however, there is nothing novel or interesting about the data presented that seems to warrant publication. Consider changing this to a systematic review of the literature.

Thank you for the comments. We agree that a systematic review is better than a narrative review. The heterogeneity of findings with each different robotic manipulation ergonomic factor would make analysis less reliable. We have performed a comprehensive search for evidence with regards to each ergonomic factor and presented the results without introducing our biases. The narrative review should provide a comprehensive overview for all surgeons and provide research-based evidence of the perceived manipulation ergonomic benefits of robotic surgery for robotic surgeons.

Reviewer B

The content, particularly in the paragraph titled "Lack of Haptic Feedback. Has a lot of similarities to the book chapter.
So, the content needs to be rephrased

We thank Reviewer B for the comment. We have rephrased the whole paragraph. We have included the new and old paragraphs side-by-side for review.

Haptics refers to feedback received through touch that relates to various properties of a tissue. Kinesthetic haptic senses forces and torques in the joints, muscles, and tendons. Tactile haptics involve senses such as compliance, viscosity, surface texture, pressure distribution and deformation which are detected by mechanoreceptors under the skin.[53] Haptics require sensors on the patient-robot side to acquire information and displays to convey this information to the surgeon. The location of the sensing element can be outside the abdominal wall near the actuation mechanism driving the end-effector (indirect) or inside the patient at the instrument tip, embedded on the end-effector (direct). Indirect force sensing can be achieved by sensors in the robotic arms or by computer analysed visual cues.[40] The delicate surgical end-effector forces needed to give precise feedback to the surgeon makes intra-abdominal direct sensing the better option but has the disadvantage of requirement to be small and sterisable.[54]
One of the main disadvantages of the robotic system is elimination of force and tactile cues. Lack of haptic feedback can result in excessive or inadequate application of force, causing damage or slippage of tissues.[55] Tactile feedback resulted in significantly decreased grasping forces of porcine bowel (as assessed by a blinded pathologist) by both experts and novices using the da Vinci robot.[56] Haptic feedback has been shown to increase consistency, precision, and performance in robotic knot tying.[57]
Experienced robotic surgeons use visual cues like tissue deformation as surrogates for force.[58] Meccariello et al performed a study on 25 surgeons assessing their ability to recognise the thickness of custom-made membranes without use of haptic feedback.[58] They found a significant difference in performance/ average score between experts and non-experts (8.9 vs 3.6, $p<0.05$). In addition, 67% of expert surgeons correctly identified the location of a metal clip in the correct quadrant of a membrane compared to 37% of non-experts. Restoration of three-dimensional vision may be important to compensate for loss of force feedback.[59]
The da Vinci Surgical System currently does not offer haptic feedback. Some of the newer robotic systems such as Senhance offer haptic force feedback. Studies have indicated safety in its use for colonic resections but there has been no direct comparison with no haptic feedback systems.[60] Another application of haptic feedback is the creation of a surgical corridor with virtual boundaries within which surgeons can operate safely in and avoid delicate anatomical structure.[53]

Lack of haptic feedback is a disadvantage of robotic surgery with the da Vinci system. Haptic feedback can be kinesthetic (which senses forces and torques) or tactile (which senses pressure and deformation).[53] To acquire haptic feedback during RS, sensors to acquire information and displays to convey this information to the surgeon are required. The location of the sensing element can be outside the abdominal wall in the robotic arms (indirect) or at the instrument tip (direct).[40] Intra-abdominal direct sensing can offer more precise feedback but is disadvantaged by the need to be small, durable, and sterisable.[54] Another application of haptic feedback is the creation of a surgical corridor with virtual boundaries within which surgeons can operate safely in and avoid essential anatomical structures.[53]

Lack of haptic feedback can result in application of excessive force causing tissue trauma or inadequate gripping force.[55] The surgeon can overcome some of the force problems by knowing which da Vinci robotic instrument to use for grasping different tissues because the grip force is different with each instrument. The addition of haptic feedback during simulation RS has been shown to improve performance, reduce grasping forces on porcine bowel, and increase consistency and precision during knot tying.[56,57] Experienced robotic surgeons can operate efficiently and safely without haptic feedback by unconsciously using visual cues like tissue deformation as surrogates for force.[58] Restoration of three-dimensional vision is an important compensatory factor.[59] Some of the newer robotic systems such as Senhance offer haptic force feedback, but there has been no non-simulated studies comparing surgeon performance with and without haptic feedback.[60]

Reviewer C

This is a good paper and an interesting topic that has not been addressed as comprehensively prior to this.

We thank Reviewer C for the support.

Some suggestions for improvement are made below:

Throughout the text various mentions are made of 6 or 7 degrees of freedom interchangeably. Do robotic instruments provide 6 or 7 dof?

Thank you for pointing this out. Some consider grip as a seventh degree of freedom. We have made it clearer in the "Degrees of freedom" section.

Instrument actuation (with the gripping action of grasping instruments) is sometimes considered the seventh DOF.

Introduction -

The importance and novelty of this paper should be highlighted more in the Introduction section. The practitioner summary mentions that prior papers have addressed posture ergonomics, visualisation, and workflow, but the Intro does not mention these prior papers or highlight the lack of previous reviews of manipulation ergonomics. The Intro could be bulked out a bit more in general.

We have taken the reviewer comments on board and added an extra paragraph with 6 extra references to address this.

Improved ergonomics for the operating surgeon may be an advantage of robotic surgery (RS). Ergonomics has been classified as having physical, organisational, and cognitive components. Previous review articles have addressed postural, visualisation, cognitive and workflow ergonomics associated with RS. RS offers postural advantages to the surgeon with its seated positioning and ability to support the forearms on the console bar. A meta-analysis revealed the biceps as the only muscle group that consistently demonstrated significantly lower muscle activation for RS when compared with laparoscopic surgery.[1] Other postural ergonomic benefits of RS include distribution of upper limb muscle fatigue to the non-dominant side and ability to take micro-breaks.[2,3] Visualisation ergonomic advantages of RS include better exposure, immersive three-dimensional (3D) vision, surgeon camera control, and line of sight screen location.[4] Other visualisation ergonomic considerations include stereo-acuity, sensory mistatch, visuospatial ability, and visual fatigue. Separation of the surgeon from the patient and team members Is the main contributor for flow disruptions (FDs) in RS.[5] There may be an association between FDs and task error rate. Intervention to counter FDs include training, operating room adjustments, checklists, teamwork, communication improvement, ergonomics, technology, guidelines, workflow optimisation, and team briefing. The impact of robotic assistance on cognitive workload is complex.[6] The better associated postural, visualisation and manipulation ergonomics may facilitate less need to delegate cognitive resources to the physical tasks, but this may be offset by reduced situational awareness related to physical separation, communication difficulties, need to control more instruments, limited visual field and lack of haptic feedback.

Methods -

Need to cite your search strategy table (currently labelled as Table X) as there is currently no reference to this in the text. Also, could highlight here that this is a narrative review even though it does state this in the title of the paper.

We have incorporated more information in the methods and highlighted the review as being narrative.

A literature search was conducted in September 2023, using MEDLINE (Pubmed) for this narrative review. All studies published from inception to September 2023 were considered and no restrictions was imposed regarding study design. Only English language papers were reviewed. To find relevant publications, keywords 'manipulation', 'ergonomics', and 'robotic surgery' were used. Other keywords used were extracted from previous review articles on ergonomics and robotic or laparoscopic surgery. These keywords are used as subheadings in the discussion. The other search terms used were degrees of freedom, fulcrum, tremor, scaling of movements, ambidexterity, camera control, fourth arm, hand controllers, instruments, haptic feedback, and robot arm clashes. In addition, a hand search of references cited in the studies and reviews was conducted to ensure literature saturation. Original articles published in peer-reviewed journals were considered.

Discussion -

The discussion of degrees of freedom is a little confusing / hard to follow. Perhaps an image here demonstrating the different movements would help? As noted above, clarify whether robotic surgery provides 6 or 7 dof.

We have tried to make the DOF movements clearer with more descriptions. We have clarified the use of 6 or 7 dof (see above).

Degrees of freedom (DOF) is the potential for independent movement in a particular direction or rotation. Open surgery allows the use of all six DOF (along the translational x-y-z axis and orientation around the rotational roll-pitch-yaw axis).[13] Laparoscopic instruments offer four DOF: rotation or roll along the long axis, in and out, side to side (yaw) and up and down (pitch).[12] Instrument actuation (with the gripping action of grasping instruments) is sometimes considered the seventh DOF. With laparoscopic surgery, two of the possible three translational DOF are lost due to restrictions imposed by the trocar entry point which only allows one path to reach a point inside the abdominal cavity (along the trocar direction only).

The articulated instruments used in robotic system have an additional two DOF due to an extension/ flexion and a tilt function at the distal wrist.[14]

Line 181 is incorrect. Hugo does not allow camera control through head movement, it just prevents the robot moving when the surgeon looks away from the screen.
Thank you for the correction. The sentence has been altered.
The TransEnterux Surgical Senhance offers camera control by eye movements through an infrared eye-tracking system.[34] The Da Vinci and Medtronic Hugo surgical systems have an inbuilt safety mechanism which suspends robotic arm movement when the surgeon looks away from the screen.[35]

Line 309 – the company is called CMR, not Cambridge Medical Robotics (name changed in 2018).
Thank you. It has been changed in the manuscript.
Arm clashes can be avoided more easily with robotic systems which use individual patient carts for each arm (such as with the Senhance, Hugo, and CMR Versius systems).

The section on Manipulation Ergonomics and Laparoscopic Surgery could come earlier as this partly helps to explain the need for the paper, and introduces several of the topics that will be covered in more detail in the text.
We have moved this section to the first paragraph in the Discussion.

I would recommend this paper for publication once these changes have been made.

Reviewer D

The authors have submitted a narrative review on the 'advanced technology' involved in robotic-assisted surgery.

Unfortunately, there are already countless publications with significantly more in-depth analysis of the topic.

We thank the reviewer for the review. This narrative review is the first of its kind to report on manipulation ergonomics and robotic surgery research. The reviewer may be alluding to studies which have reported on the different individual subsection topics of this paper. Our review has researched and assembled the findings (of 63 referenced peer-reviewed journal articles and many that were not included) into one review article. In addition, there are review articles on ergonomics and robotic surgery involving posture, visualization, cognition, and workflow; as well as review articles on manipulation ergonomics and laparoscopic or open surgery.