SPANDIDOS PUBLICATIONS

Ergonomic and sustainable posture for gynecological laparoscopic surgeons determined based on images analyzed using artificial intelligence

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Received March 12, 2024; Accepted June 19, 2024

DOI: 10.3892/br.2024.1862

Abstract. Studies have reported the emergence of work-related musculoskeletal disorders (WMSD) due to surgery. In fact, the usfige of long-shafted instruments has been suspected to induce WMSD in laparoscopic surgery. The present study therefore investigated whether differences in the range of motion of the face and neck, and the shoulder, elbow and hand on the dominant hand side, existed when using short- and long-shafted laparoscopic coagulation shears (LCS) during a gynecological laparoscopic surgery, based on images analyzed using artificial intelligence. After identifying the corresponding body parts in the video, the range of motion was illustrated graphically for each joint coordinate, followed by statistical analysis for changes in the position of each part. The range of motion for the face and neck did not significantly differ, whereas those for the shoulder, elbow and hand became noticeably broader when using the 36-cm long-shafted LCS than when using the 20-cm short-shafted LCS. Overall, the shorter LCS promoted a narrower range of motion compared with the 36-cm LCS, suggesting its potential for reducing the physical strain placed on the surgeon's body during gynecological laparoscopic surgery.

Introduction

Although laparoscopic surgery has become a popular surgical option given its reduced burden on the patient, studies have noted the occurrence of work-related musculoskeletal disorders (WMSD) due to laparoscopic surgery (1,2). WMSD of surgeons is prevalent, with rates ranging from 66 to 94% for open surgery and from 73 to 100% for conventional laparoscopy. In open surgery, WMSD is due to musculoskeletal posture, especially involving the neck (1,3). Open surgeries are associated with larger neck angles compared with laparoscopic surgeries. There are also risk factors in open surgery such as the use of loupes, headlamps and microscopes, whereas in laparoscopic surgery, in developing WMSD, the estimated unique risk factors include table and monitor position, long-shafted instruments, poor instrument handle design, the small hands of surgeons and increased patient body mass index (BMI) (4).

Bell-land General Hospital (Sakai, Japan) uses laparoscopic coagulation shears (LCS) as an energy device for gynecological laparoscopic surgery. Harmonic ACE® shears (Ethicon US, LLC; Johnson and Johnson MedTech) with a shaft length of 36-cm are usually used as the LCS when performing total laparoscopic hysterectomy, despite some gynecological surgeons stating that a short-shafted (i.e., a 20-cm LCS) is more useful (5), as it helps surgeons effortlessly maintain their shoulder position during gynecological laparoscopic surgery. However, no reports have objectively evaluated the benefits of using a short-shafted energy device for gynecological laparoscopic surgery. In laparoscopic surgery, the motion of the surgeon is restricted by the positioning of the abdominal ports, and depends on table and monitor position, shaft length of the instruments and instrument handle design, among other factors (1,3). The ergonomic evaluation of a surgeon's motion in laparoscopic surgery is considered to be meaningful, but remains unknown without actual measurements. The present study attempted to qualitatively capture surgeon discomfort and strain when comparing differences between using two different instrument lengths.

The present study investigated whether differences in the range of motion of the face, neck, right shoulder, right elbow and right wrist existed when using an LCS with a short 20-cm

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Key words: musculoskeletal disorders, long-shafted laparoscopic coagulation shears, short-shafted laparoscopic coagulation shears

shaft and a conventional 36-cm shaft during a gynecological laparoscopic surgery, based on images analyzed using artificial intelligence (AI).

Materials and methods

Laparoscopy. A 20-cm short-shafted Harmonic HD® (Ethicon US, LLC; Johnson and Johnson MedTech) and a 36-cm long-shafted Harmonic ACE (Ethicon US, LLC; Johnson and Johnson MedTech) were switched between halfway through the dissection of the right-sided uterine broad ligament, with the surgeon's actions being video recorded (Fig. 1).

Matlab's OpenPose® (version R2023a; The MathWorks, Inc.) was used to analyze human postures by identifying the coordinates of specific joints, including the head, neck, right shoulder, right elbow and right hand, within images generated by the video. After pinpointing these joints, their trajectories were plotted to visually represent their movement over time. To assess the movement distance of each joint, the distance on a plane was calculated from their median values, allowing the precise quantification of their motion (Fig. 2).

OpenPose employs a sophisticated algorithm that starts by detecting individual body parts within an image, such as the nose and left elbow. Following this initial identification, it adopts a bottom-up approach, assembling individual figures by piecing together these body parts into reasonable combinations (6). This method enables the accurate estimation of the human posture, even in images with several people, by analyzing how these body parts come together to form individual poses. This approach was instrumental in the present analysis, offering a detailed understanding of human posture and movement in various scenarios.

An identical duration (2 min) of the same laparoscopic hysterectomy procedure was separately analyzed when using the long-shafted and the short-shafted LCS, and the surgeon's motions during this period were analyzed with OpenPose. The range of motion for the face, neck, shoulder, elbow and the hand on the side using the device was also analyzed in a physician with limited years of experience (in training for certification) who performed a dissection of the left-sided broad ligament of the uterus. Surgical procedures were performed as a set sequence of movements, and comparisons were made between similar surgical procedures.

Statistical analysis. The data acquired by OpenPose are presented as the median (IQR). Continuous variables with non-parametric distributions were analyzed using Wilcoxon signed-rank test for the paired data. All statistical analyses were performed using JMP® software, version 16 (SAS Institute, Inc.).

Ethics. With regard to the use of a human surgery case for research, the present study was conducted following the ethical principles of the Declaration of Helsinki, and with the approval of the Ethical Committee of Belland General Hospital (Sakai, Japan; approval no. 2023-0021). A comprehensive explanation was provided to the patient involved in this study before obtaining written consent for the academic use of their surgical records.

Results

One case of hysterectomy surgery was used for the present study and analyzed. The patient was 52-year-old woman (gravida 1, para 1), with a height, body weight and BMI of 156 cm, 59 kg and 26.2 kg/m^2 (normal range, 18.5 to 25 kg/m^2), respectively. A total laparoscopic hysterectomy was performed due to myomas. The surgeon stood on the left side of the patient, the surgical assistant stood on the right side of the patient and the assistant handling the manipulator for uterine manipulation stood between the patient's legs. During the surgery, the study hypothesis that a shorter instrument shaft will result in less movement of the joints was tested.

During the procedure, the surgical motions were compared for a trainee surgeon and an experienced surgeon.

The range of motion for the face and neck did not notably differ between the 20-cm short-shafted LCS and the 36-cm long-shafted LCS; however, the range of motion for the shoulder, elbow and hand became notably broader when using the long-shafted LCS compared with that when using the short-shafted LCS (Figs. 3 and 4). The distance traveled from the center of the shoulder, elbow and hand joints was significantly smaller with the short-shafted LCS than with the long-shafted LCS ($P<0.0001$; Fig. 5).

The range of motion for the face, neck, shoulder, elbow and the hand on the side using the device was also analyzed in a physician with limited years of experience (in training for certification) who performed a dissection of the left-sided broad ligament of the uterus. Similarly, the results in a physician with limited years of experience showed that the range of motion for the shoulder, elbow and hand was wider with the long-shafted LCS than with the short-shafted LCS (Figs. 6 and 7). Furthermore, comparing the aforementioned results with those in the more experienced surgeon revealed that the head, neck, shoulder, elbow and hand all had a greater range of motion. Furthermore, the distances traveled from the center of the shoulder joint and the center of the hand joint were significantly smaller with the long-shafted LCS than with the short-shafted LCS ($P<0.0001$), whereas no significant difference was observed between the types of LCS for the moving distance of the elbow joint (Fig. 8).

Discussion

WMSD, which is prevalent among surgeons performing gynecological surgeries, refers to repetitive motion injuries that may damage the muscles, nerves and joints, commonly affecting the neck, shoulders, back and hands. In addition to chronic pain, these disorders may decrease job satisfaction and productivity. Factors that can contribute to musculoskeletal disorders include increased patient BMI, small hand size of surgeons, especially female surgeons, and the design of surgical instruments and energy devices. Therefore, establishing measures to address musculoskeletal disorders is essential (1,2,4,7).

By analyzing images using AI, the current study evaluated the impact of LCS shaft length on the range of motion of the neck, shoulder, elbow and hand, which is considered crucial to minimize strain. First, to trace of the movements of the face and and neck, and the shoulder, elbow and hand on the side using the device during surgery, deep learning AI was

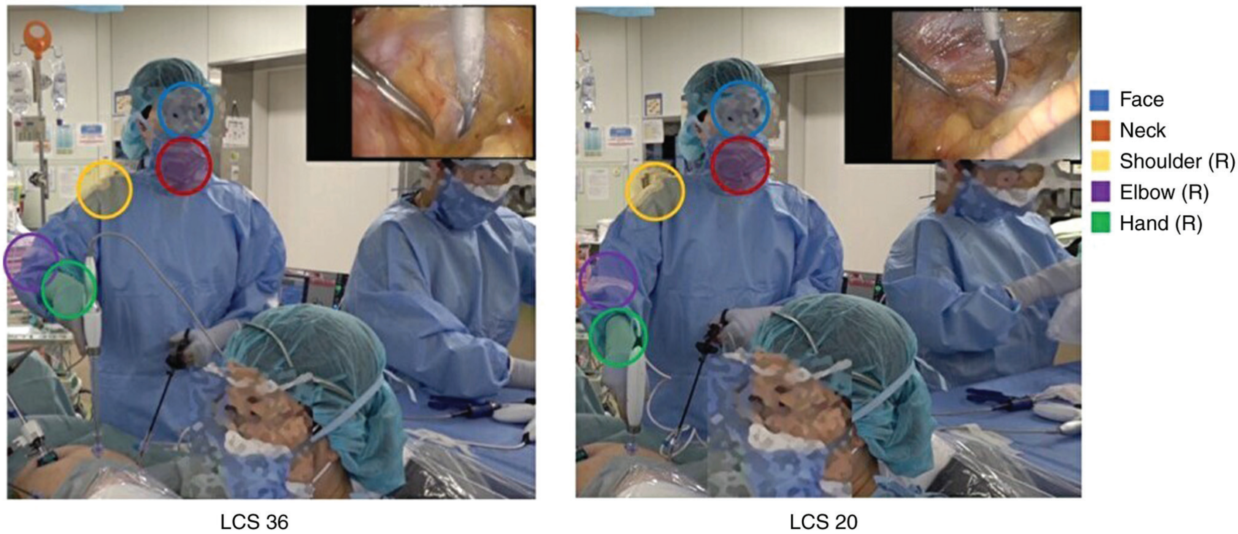

Figure 1. Images captured from a video of an experienced surgeon showing marking by AI of the face and neck, and the shoulder, elbow and hand on the side using the device. AI was used to identify body parts in the video, with the range of motion being illustrated graphically for each joint coordinate. Blue circle, face; red circle, neck; yellow circle, shoulder; purple circle, elbow; green circle, hand. R, right side; AI, artificial intelligence; LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

Figure 2. Human posture analysis in an experienced surgeon. Human postures were analyzed identifying the coordinates of specific joints (indicated by green marks), including the head, neck, right shoulder, right elbow and right hand, within images generated by the video. After pinpointing these joints, their trajectories were plotted to visually represent their movement over time.

employed using MATLAB software. To identify body parts in an image, OpenPose uses a pretrained neural network that predicts heatmaps and part affinity fields for body parts in an input image. The images were cut from the video and adapted to the neural network. Range of motion (pixels) was illustrated graphically for each joint coordinate, and statistical analysis was performed to determine changes in position. Figs. 4 and 7 illustrate the distance traveled from the center of the joints, depicting the percentage change from the center to the tip.

The present study findings showed that the short-shafted LCS promoted a smaller range of motion than the long-shafted LCS. The association between a narrower range of motion and a reduction in WMSD is not directly described in the literature. Manasnayakorn *et al* (8) reported that the use of short-length needle holders in laparoscopic surgery leads to less muscle workload. It is possible that a small range of motion is a result of use of short-shafted instruments, and is a factor for reduced muscle workload, which is caused by short-shafted devices during laparoscopic surgery. Manasnayakorn *et al* (8) also investigated the operation speed and accuracy when using short-length needle holders. It was concluded that short-length devices may lead to improved execution time and that the accuracy of operative motion with short-length devices is not different from that of standard-length devices.

It is necessary to evaluate whether a broader range of motion with the long-shafted LCS has any disadvantages in terms of surgical precision and efficiency. In future, any wobbling of the tip of the instrument and the surgical duration should be assessed. When using a long-shafted instrument, instability of the upper limb and device tip wobbling are anticipated. Comparisons of the range of motion of the device tip of two instruments with different shaft lengths should be considered. It is possible that one of other factors that causes WMSD is the time that the limb is held in a difficult position against gravity. Bell-land General Hospital has recorded cases of adhesion due to conditions such as endometriosis within the abdominal cavity, where adhesiolysis surgery was performed for a prolonged period and the limb was held in a difficult position, increasing fatigue as the surgery duration lengthened. In the future, it is necessary to consider comparisons of surgical duration with two instruments of different shaft lengths, to

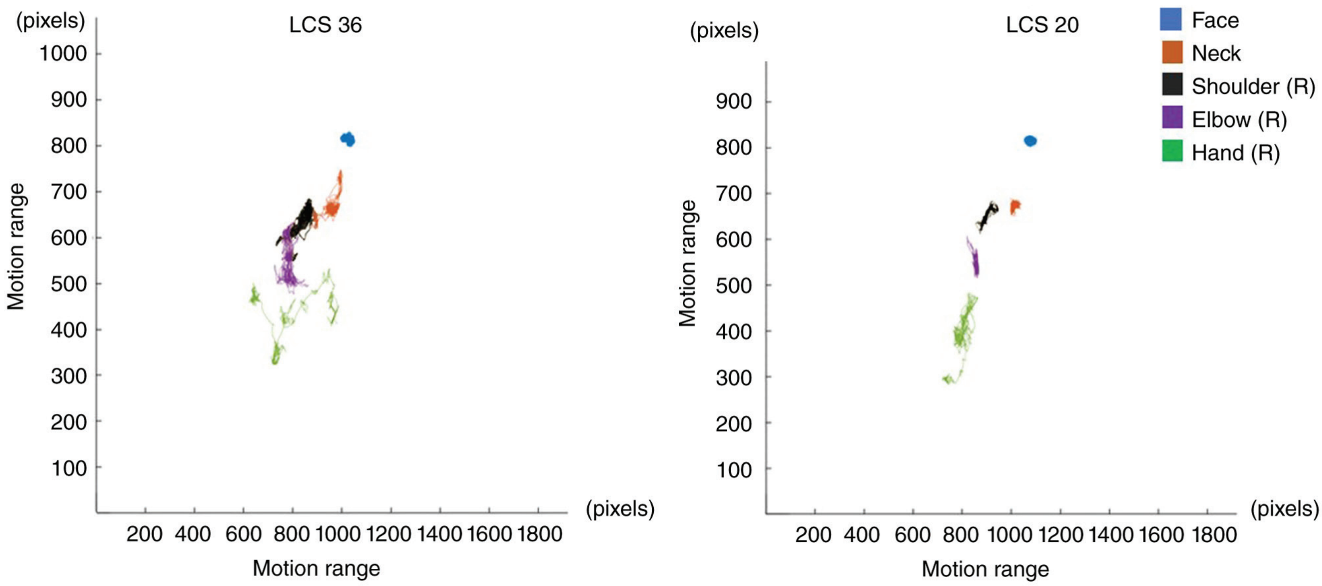

Figure 3. Range of motion in an experienced surgeon during the use of the 36-cm long-shafted LCS and the 20-cm short-shafted LCS. The range of motion for the face and neck did not significantly differ, whereas that for the shoulder, elbow and hand became noticeably broader when using the longer LCS compared with that when using the shorter LCS. R, right side; LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

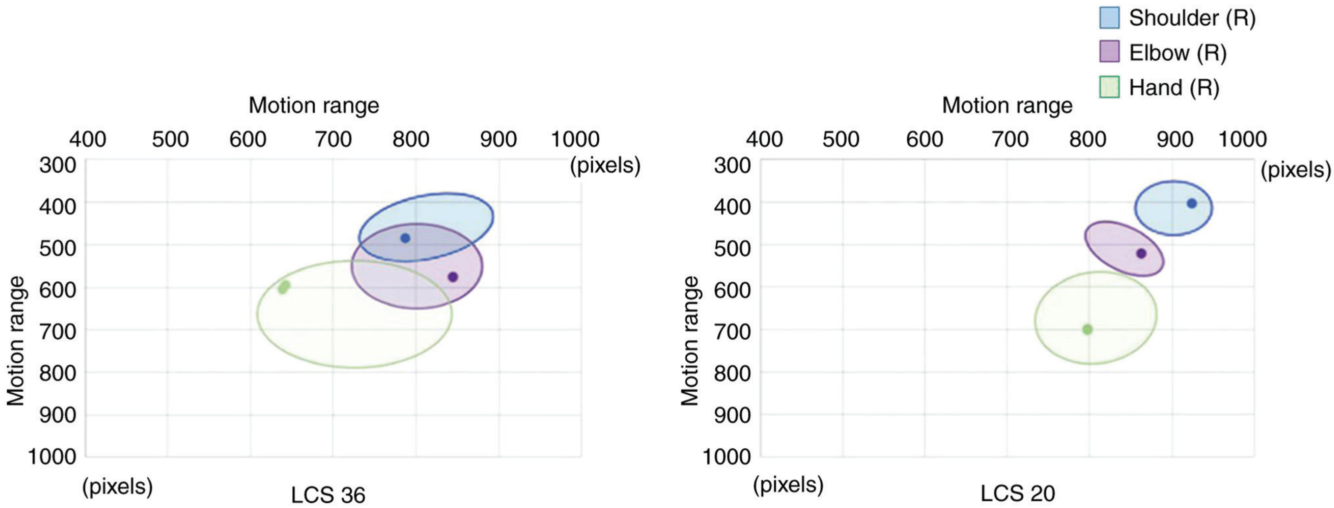

Figure 4. Differences in posture in an experienced surgeon during the use of the 36-cm long-shafted LCS and the 20-cm short-shafted LCS (changes in shoulder, elbow and hand). The circle in the figure show ranges of the motion of each joint, and the dot in the circle represents the most frequent position of each joint. The range of motion for the shoulder, elbow and hand became notably broader with the longer LCS than with the shorter LCS. R, right side; LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

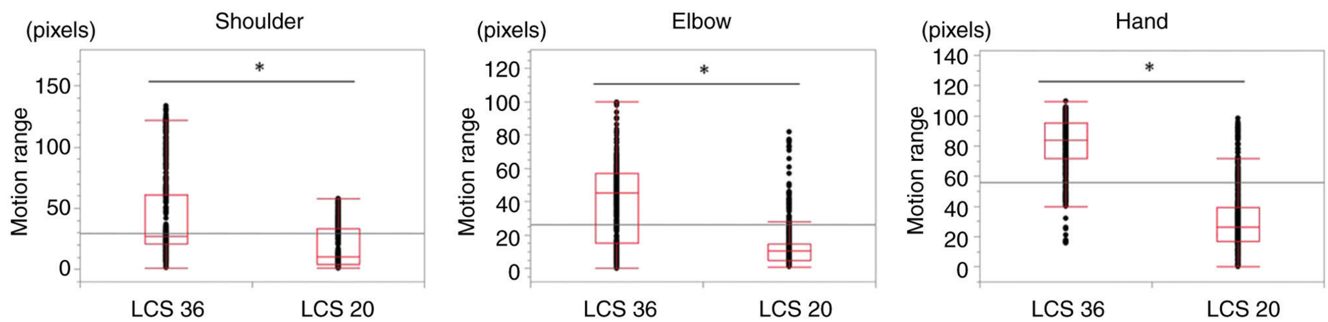

Figure 5. Distance traveled an experienced surgeon from the center of the joints with the 36-cm long-shafted LCS and with the 20-cm short-shafted LCS (changes in the coordinates of the shoulder, elbow and hand). The travel distance was significantly shorter with the shorter LCS than with the longer LCS in all joints. *P<0.0001. LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

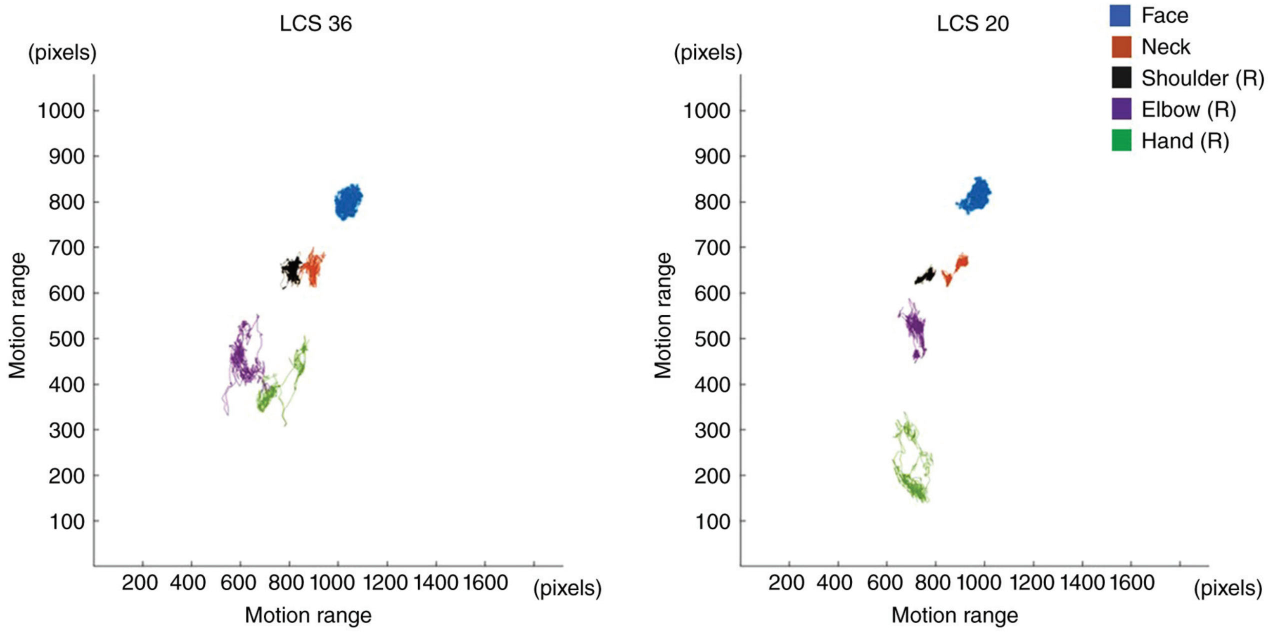

Figure 6. Range of motion during the use of the 36-cm long-shafted LCS and 20-cm short-shafted LCS in a physician with limited years of experience (in training toward certification). The range of motion for the shoulder and elbow was broader with the longer LCS than with the shorter LCS. LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

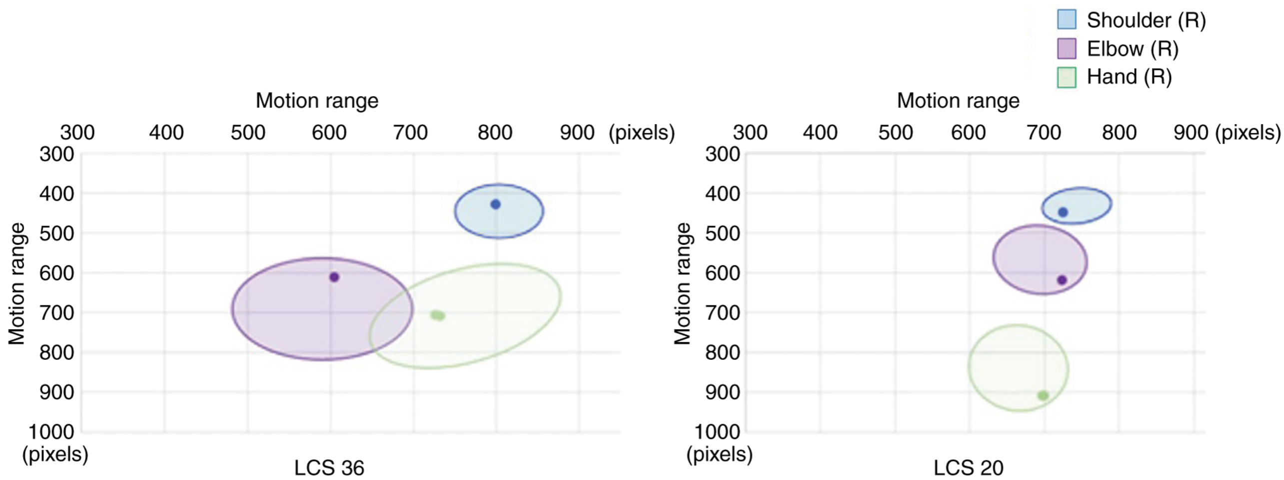

Figure 7. Difference in posture during the use of the 36-cm long-shafted LCS and 20-cm short-shafted LCS (changes in shoulder, elbow and hand) in a physician with limited years of experience (in training toward certification). The circle in the figure show ranges of the motion of each joint, and the dot in the circle represents the most frequent position of each joint. The range of motion for the shoulder and elbow was broader with the long LCS than with the short LCS. R, right side; LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

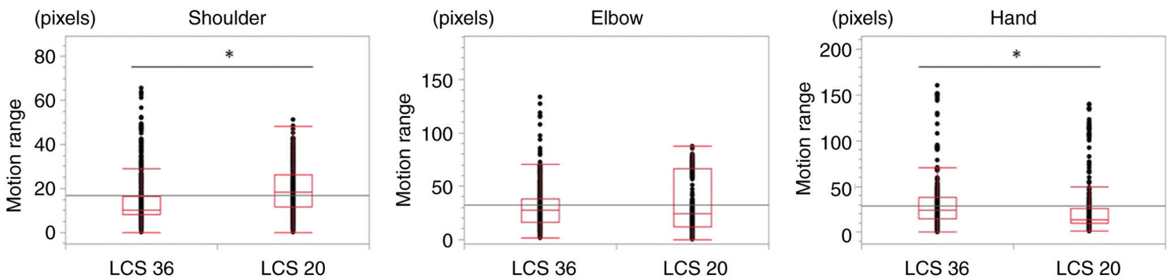

Figure 8. Distance traveled from the center of the joints during the use the 36-cm long-shafted LCS and 20-cm short-shafted LCS (changes in coordinates of the shoulder, elbow and hand) in a physician with limited years of experience (in training toward certification). The distance traveled from the center of the joints showed varying results, with the shoulder showing a longer travel distance with the short LCS than with the long LCS, the elbow having a similar distance with both types of LCS, and the hand having a shorter distance with the short LCS than with the long LCS. *P<0.0001. R, right side; LCS 36, 36-cm long-shafted laparoscopic coagulation shears; LCS 20, 20-cm long-shafted laparoscopic coagulation shears.

determine, for example, whether using LCS with a shorter shaft results in shorter surgical times.

In the present analysis, the physician who performed the dissection of the right-sided broad ligament of the uterus was a qualified and certified laparoscopic surgeon with extensive experienced in the field. The range of motion for the face, neck, shoulder, elbow and hand was also analyzed in a physician with limited years of experience (in training for certification) who performed a dissection of the left-sided broad ligament of the uterus. The results in the physician with limited years of experience similarly showed that the range of motion for the shoulder, elbow and hand was wider with the long-shafted LCS than with the short-shafted LCS. Comparing the results with those in the more experienced surgeon revealed that the head, neck, shoulder, elbow and hand all had a greater range of motion. Furthermore, the distance traveled from the center of the shoulder and hand in the less experienced surgeon was significantly smaller with the long-shafted LCS than with the short-shafted LCS, whereas no significant difference was observed for the elbow between both types of LCS. However, in the more experienced surgeon, the range of motion for every joint was significantly smaller when using the short-shafted LCS than when using the long-shafted LCS. These results suggest that factors potentially hindering the effective use of surgical instruments, such as surgeon left-handedness or limited/fewer years of surgical experience, may have contributed to the observed variability.

One study on gynecological oncologists revealed that 88% of the participants reported pain from laparoscopy, with 29% seeking treatment (9). Static posture, excessive shoulder internal rotation, elbow deviation and hand deviation are more common in laparoscopic surgery than in open surgery (10,11). As assessed by electromyography in a previous study, greater forearm, deltoid and thenar muscle force is required during laparoscopic surgery than during open knot tying and grasping (12,13). Furthermore, the ideal monitor position was reported to be below the surgeon's eye level, at a distance of 60 cm from the front of the surgeon (11,14,15). This clearly indicates that the surgeon's posture, the height of the surgical field and the position of the monitor are important when performing the surgery.

A limitation for the present study is that it only evaluated one case performed by one surgeon. Further verification on multiple cases by multiple surgeons is necessary in the future.

In conclusion, the current study examined the differences in posture and range of motion when using a 20-cm short-shafted LCS and a 36-cm long-shafted LCS, in a single case of laparoscopic hysterectomy. Notably, the findings showed that the short-shafted LCS promoted a narrower range of motion than the long-shafted LCS, indicating the possibility of reducing the burden placed on the surgeon's body during surgery.

As minimally invasive laparoscopic surgery becomes more prevalent, ongoing efforts to explore innovations to improve WMSD are necessary. The present findings would suggest room for further exploration and refinement to improve the ergonomics of surgical instruments and help reduce the incidence of WMSD during evolving gynecological laparoscopic surgery.

Acknowledgements

Not applicable.

Funding

No funding was received.

Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

MO was responsible for writing the manuscript and preparation of the sample dataset, including the analysis and interpretation of the data. NM was responsible for study design, interpretation of the results and study supervision. ST, MM, KM, TM, AI and JO were responsible for preparation of the electric sample dataset for the movement distance of each joint analyzed by OpenPose, including the analysis and interpretation of the data. TM supervised the study, and checked and fixed the final manuscript. All authors have read and approved the contents of the manuscript. MO, NM, ST, MM, KM, TM, AI, JO and TM confirm the authenticity of all the raw data.

Ethics approval and consent to participate

The present study was conducted following the ethical principles of the Declaration of Helsinki, and with the approval of the Ethical Committee of Belland General Hospital (Sakai, Japan; approval no. 2023-0021). A comprehensive explanation was provided to the patient involved in this study before obtaining written consent for the academic use of their surgical records.

Patient consent for publication

The patient provided written consent for their information to be published.

Competing interests

The authors declare that they have no competing interests.

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