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Upper body position analysis of different experience level surgeons during laparoscopic suturing maneuvers using optical motion capture

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ABSTRACT

Background: This study aimed to analyze the posture patterns of surgeons with two different skill levels during laparoscopic surgery using an optical motion capture system.
Methods: Twenty participants were divided into novice and expert groups. Their upper body motions during suturing tasks were captured, including average angle and angle variability (shoulder, elbow, wrist), joint fixation, head movement, and thoracolumbar flexion angle.
Results: Our analysis showed that (1) the arms of the expert surgeons were more loosely held at their sides by about 7°; (2) their elbows were more bent by about 10°; (3) they had a greater change in shoulder angle by about 1.4 times and a more fluid posture; (4) their heads were more stable, particularly in the longitudinal and vertical axes; and (5) their thoracolumbar flexion angle was smaller by about 10°.
Conclusions: The posture patterns of different technical level surgeons during laparoscopic suturing maneuvers revealed differences in limb positions. These results may provide new insights into the efficient acquisition of technical skills and reduced physical stress during laparoscopic surgery.

Introduction

In laparoscopic surgery, surgeons need to overcome difficulties such as loss of depth perception, hand-eye coordination, and instrument manipulation in a limited space.[1] With the progress in engineering technology, various analyses have been carried out with the aim of establishing appropriate ways to teach laparoscopic surgical techniques. In surgical education, understanding the technical differences of surgeons numerically may help in its transfer and improvement. There have been reports of many laparoscopic technical analyses such as on the magnitude of the force at the legation point while suturing during laparoscopic surgery,[2,3] the force direction of laparoscopic dissection skill by instrument tip,[4] and the ways to move the forceps tips (path length, speed, acceleration and degrees of freedom of motion).[5–7] Conventionally, expert surgeons have acquired the techniques and tips to perform these procedures through experience, which are not easy to convey. The quantification of such data using an objective index may be beneficial for novice surgeons in mastering these surgical techniques.

One important technical analysis is on the posture of the body during surgery. The science of ergonomics for posture analysis has been discussed from the 1950's to create a comfortable work environment.[8] In recent years, with the advent of inexpensive motion capture systems, motion analyses have been performed in various fields. In the surgical field, motion analyses using optical motion capture in gastrointestinal endoscopy,[9,10] laparoscopy,[11,12] and robotic surgery[13,14] have been reported. As for laparoscopic surgery, posture analysis of the cervical and thoracolumbar spine using an electromagnetic tracking device between two operation setups (laparoscopic cholecystectomy) and video-based analysis of joint movement in live gynecological surgery have been reported. However, there have been few reports focusing on the posture patterns of different level surgeons. Although previous reports have evaluated joint angles two-dimensionally by video-based assessment, comprehensive three-dimensional upper limb position analyses using motion capture systems during laparoscopic surgery have not been extensively performed.

We hypothesized that the position patterns of joint angles during laparoscopic surgery may differ depending on the skill level of the surgeon. For example, novice surgeons may operate in a nonoptimal posture, slouch while looking into the monitor, have

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unstable head position, or extremely stretch or bend their joints. In this study, using an optical motion capture system, we analyzed three-dimensionally the characteristics of the posture patterns of the upper body in two groups of gastrointestinal surgeons with different levels, while performing laparoscopic suturing tasks in a box trainer. Because measurements during a live surgery may have many biases such as difficulties of the surgery or patient position, we used a box trainer and evaluated the most basic and simple suturing tasks to facilitate the evaluation of the differences in three-dimensional upper limb positions. Understanding these characteristics may be helpful for novices not only to acquire “tips” in performing laparoscopy, which experts have already mastered, but also to lead to performing these procedures with competence while decreasing musculoskeletal fatigue.

Materials and methods

The Ethics Committee of Kansai Medical University, Osaka, Japan approved the study protocol (protocol number 922). All 20 gastrointestinal surgeons were recruited for this study at a domestic conference (Japan Society for Endoscopic Surgery). They were divided into two groups: 10 surgeons with novice laparoscopic experience [1–5 years (median 4 years); 1–30 cases (median 15 cases)] and 10 surgeons with wide laparoscopic experience [10–30 years (median 19 years); ≥100 cases (median 250 cases)]. The expert surgeons were certified to have sufficient skills to perform safe operations by the Endoscopic Surgical Skill Qualification System in Japan. There was no significant difference in body height and weight between the two groups.

All participants completed needle driving, one double-knot, and five single-knot sequences using a standard laparoscopic needle driver (k26173; Ethicon Endo-surgery, Cincinnati, OH, USA) with Vicryl 3-0 SH (J527H; Johnson & Johnson, Somerville, NJ, USA) cut to lengths of precisely 15 cm. A slit Penrose drain recommended by the Society of American Gastrointestinal and Endoscopic Surgeons (Part 50302; Limbs & Things Inc., Savannah, GA, USA) was used as the suturing target. All surgeons were instructed to perform these tasks accurately within 500 s. They were not informed which parameters were being evaluated. The height of the platform on which they stood was adjustable.

The participants' upper body motions during the suturing tasks were captured with a commercially-available optical motion-tracking system OptiTrack Flex3 (Natural Point, Inc., Corvallis, OR, USA) using six infrared cameras and spherical retroreflective markers of 14 mm diameter. Marker information was outputted as XYZ data. The X-axis (X), Y-axis (Y), and Z-axis (Z) represented the longitudinal, vertical, and lateral axes, respectively. A sampling frequency of 100 Hz was used to capture the tracking data from each marker. Postprocedural processing of the kinematic data was performed using Motive:Body (NaturalPoint, Inc.). Sixteen markers were used to track the forehead, shoulder, elbow, wrist (lateral and medial), hand, and hip for motion capture (Fig. 1A). All marker trajectories that vibrated faster than 6 Hz frequency were smoothed. Six infrared cameras were placed evenly at intervals of about 2.5 m around the subject without a dead angle (Fig. 1B). Since the optical motion capture system has a very small error, we considered it suitable for analyzing precise movements such as surgical techniques.[15]

Parameters evaluated

We measured the following parameters: (1) completion time (total time and time for needle drive, double knot, and single knots); (2) average joint angle (shoulder, elbow, wrist) to assess basic upper body positioning; (3) joint angle variability (shoulder, elbow, wrist) to assess joint fixation; (4) standard variability of the three axes of the head movement range to assess the stability of the body trunk; and (5) thoracolumbar flexion angle in the sagittal plane. The movement range was defined as the standard deviation of each axis (X, Y, Z). The axillary angle was defined as the angle formed by the hip, shoulder, and lateral elbow markers. The elbow angle was defined as the angle formed by the shoulder, lateral elbow, and lateral wrist markers. The wrist angle was defined as the angle formed by two normal vectors, each consisting of three points: (1) hand, medial wrist, and lateral wrist and (2) elbow, lateral wrist, and medial wrist. The thoracolumbar flexion angle was defined as the angle formed by the forehead–hip vector and vertical vector (Fig. 1C).

Statistical analysis

All data were expressed as means ± standard deviation. Statistical analysis involved creating a bell curve using Excel 2015 (Social Survey Research Information Co., Ltd., Tokyo, Japan). All parameters were compared between the two groups using the Mann–Whitney U test. A value of $p < 0.05$ was considered to indicate statistical significance.

Results

There was a significant difference between the two groups in overall task time (expert group: 98.5 ± 19.3 s, novice group: 349.9 ± 88.3 s, $p < 0.001$). The same tendency was found for each component (needle drive, double knot, single knots).

Table 1 shows the average joint angle (shoulder, elbow, wrist). In the novice group, the shoulder angle on both sides was higher by

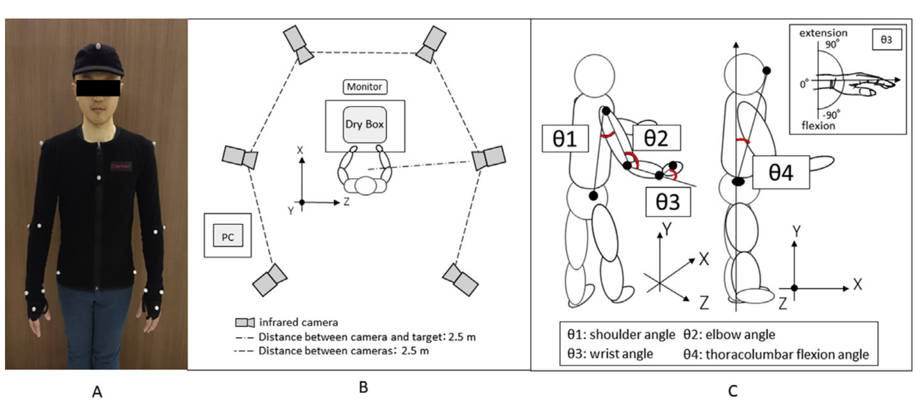

Fig. 1. A: Photograph of the positions of 16 retroreflective markers (forehead, chest, shoulder, lateral elbow, medial elbow, lateral wrist, medial wrist, hand, hip). **B:** Each participant was monitored using six infrared cameras. **C:** θ1-4 Angles were calculated from marker position information. Three-dimensional axes consisted of the following: X, longitudinal plane (back-to-forward movement); Y, vertical plane (up–to-down movement); Z, horizontal plane (side-to-side movement).

Table 1
Average joint angle (degree).

Right side	θ1 shoulder	θ2 elbow	θ3 wrist
Novice	30.7 ± 4.0	101.2 ± 7.3	25.7 ± 7.8
Expert	36.6 ± 4.9	88.7 ± 9.0	24.9 ± 8.9
p	<0.01	<0.01	ns
Left side	**θ1 shoulder**	**θ2 elbow**	**θ3 wrist**
Novice	27.6 ± 2.4	94.7 ± 8.9	22.9 ± 4.5
Expert	34.7 ± 7.4	85.6 ± 7.3	22.9 ± 8.6
p	<0.01	<0.01	ns

about 6–7°, and the elbow angle on both sides was lower by about 10–13° from those of the expert group. However, there was no difference in the average wrist angle on both sides between the two groups.

Table 2 shows the joint angle variability (shoulder, elbow, wrist). The shoulder joint angle deviation of the expert group was approximately 1.4 times larger than that of the novice group. While the experts moved their shoulder joints more fluidly, the fixation of the elbow and wrist joints did not differ between the two groups.

Fig. 2 shows the standard variability of the three axes of the head movement range.

There was a tendency for novices to have variations on the three axes, but especially, the range of the head movement in the longitudinal axis was 1.8 times greater and that in the vertical axis was 2 times greater for the novice group than the expert group. There was no significant difference between the two groups in the lateral axis.

Table 3 shows the average thoracolumbar flexion angle. The novice group was significantly more bending forward by about 10° compared to the expert group.

Discussion

We quantified, using a motion capture system, the posture patterns of gastrointestinal surgeons at two skill levels performing laparoscopic suture tasks. The revealed features of limb positioning for the expert group versus the novice group were: (1) the arms of the experienced surgeons were more loosely held to their sides, and their elbows were more bent; (2) the skilled surgeons maintained a relatively fluid posture in the upper arm; and (3) the heads of the expert surgeons were more stable, and they tended not to be in a forward-leaning posture. Thus, understanding the posture patterns of experienced surgeons may be helpful for mastering efficient operation procedures with less burden.

One of the ergonomics scores for evaluating muscle load and working posture is the RULA score.[16] According to this score, a smaller shoulder joint angle leads to less fatigue, but our study showed that the expert group had an unexpectedly larger average shoulder angle compared to the novice group (Table 1). One of its causes was that the fixation index of the shoulder joint angle was larger for experts than novices (Table 2), which suggested that the tendency for higher frequencies of movement in the shoulder might lead to an increase in the average angle. On the other hand, it has been reported that long durations of static postures were closely related to low-level muscle tension, which may contribute to an increased risk of surgeons developing musculoskeletal disorders.[17] The flexible movement of the upper arm might lead not only to manipulate the forceps efficiently but also to inadvertently contribute to reducing fatigue around the shoulder muscles.

In the RULA score, if the elbow joint is between 80 and 100°, it is defined as good posture. In our study, both groups were operating at an angle close to 90°, but the novices had an average angle exceeding 100° for the right side, suggesting that they were

Table 2
Joint fixation (degree).

Right side	θ1 shoulder	θ2 elbow	θ3 wrist
Novice	3.3 ± 0.4	7.5 ± 1.4	7.0 ± 3.1
Expert	4.8 ± 1.2	7.4 ± 1.3	7.9 ± 3.6
p	<0.01	ns	ns
Left side	**θ1 shoulder**	**θ2elbow**	**θ3 wrist**
Novice	3.4 ± 0.8	6.4 ± 1.3	6.8 ± 2.4
Expert	4.7 ± 0.9	6.8 ± 1.6	7.4 ± 2.7
p	<0.01	ns	ns

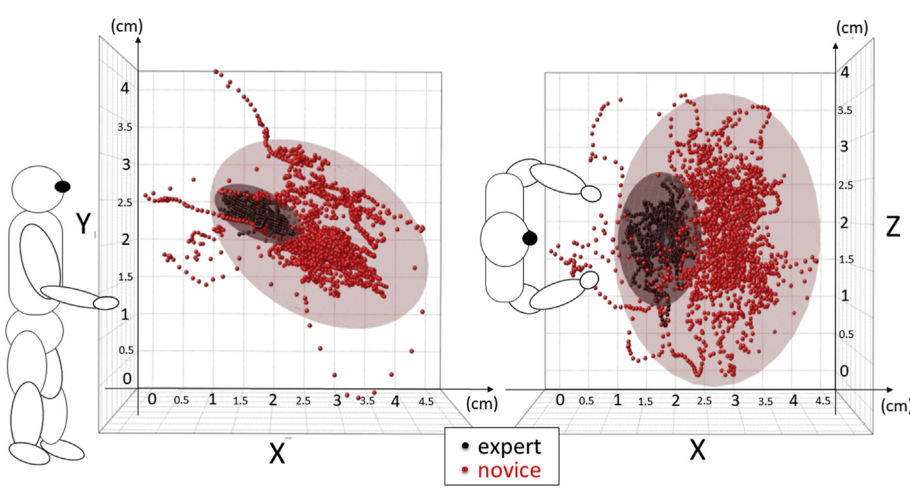

Fig. 2. Example of the trajectory of head position (one novice and one expert). Black plot: expert, red plot: novice.

Table 3
Average joint angle (degree).

	θ4 thoracolumbar
Novice	15.7 ± 7.6
Expert	5.83 ± 4.2
p	<0.01

working with a slightly high physical burden. One reason may be because the surgeons selected the height of the work table and standing positions, but the beginner surgeons not only had weaker ability but there was also a possibility that they did not understand the appropriate setting.

Regarding the wrist joint, there was no significant difference in both the average angle and fixation between the two groups. In the RULA score, it is defined that the flexion or extension of 15° or more in the wrist angle is a heavy burden, but in our study, the average wrist angle on both sides was bent by about 25° in both groups. Since there was no difference between the two groups, it was suggested that even experts were working with a heavy burden on their wrist angle. Working for a long time at such an angle might lead to wrist damage. In fact, it is known that there is burden on the wrist angle in laparoscopic surgery, and the relevance between the forceps handle design and wrist joint angle has been reported. It was also mentioned that there was a possibility that forceps with pistol type handles and adjustable handle angle laparoscopic tools can reduce the ergonomic risks of wrist musculoskeletal strain.[18,19]

Fig. 2 shows an example of the trajectory of the head position of an expert and novice. It was clearly found that the movement range of the head was larger and lacked stability in the novice. Fig. 3 shows the head movement range on three axes. The novices were largely shaking their heads in all three axes, especially in the longitudinal and vertical axes. In addition, with respect to the thoracic lumbar spine angle, the novices were leaning forward by nearly 10° compared to the experts. These results suggested that the body trunk of the novices lacked stability and they kept peering into the monitor. In the RULA score, it is defined that keeping the thoracolumbar flexion angle at −5° to 15° reduces the risk of skeletal muscle problems of the neck and waist.[11] From the viewpoint of ergonomics, it may be speculated that the posture of the experienced group exerted less burden on the body trunk besides having a more stable posture in our study (Table 3).

Some of the problems for laparoscopic surgeons are relatively more severe fatigue and musculoskeletal damage compared to robotic surgery.[20] According to a questionnaire survey targeting laparoscopic surgeons, 15–20% complained of physical discomfort in the wrist, 7–20% in the upper arm, 30–50% in the shoulder, and 40–50% in the waist.[21,22] Although appropriate monitor positions[23] and ingenuity of the handle design of the forceps have been discussed to reduce the physical load,[18,19] it is also important to understand how to move one's own body. Feedback of posture information is another method. Zhang et al. showed that it helped to improve the position of the limbs by displaying a subliminal transparent red cross superimposed to the laparoscopic images against deviant shoulder angle.[24] Yang et al. revealed that instructions about positioning with an alarm warning system (e.g., when placing an elbow on the armrest) could improve the learning curves of novices practicing on a robotic simulator.[25] Thus, visual and auditory feedback on deviated joint angles and positions may be useful for forming optimal limb positions.

Limitations

There are some limitations to this study. First, the number of participants was small. Second, the suture tasks were short and simple procedures, and we did not evaluate an actual surgery. Third, we did not consider whether understanding posture is useful for the learning curve and reduction of fatigue. In the near future, we plan to design a prospective, randomized trial to evaluate the difference in the learning curve of beginners who are given limb position information and those who are not. As for fatigue during surgery, the assessment sheet has less objectivity, and electromyography only measures the muscle activity amount, and it remains questionable whether it is suitable for assessing fatigue. An epoch-making method to quantify fatigue is required.

Conclusion

In conclusion, we analyzed the posture patterns of two skill level surgeons during laparoscopic suturing tasks using an optical motion capture system. We revealed the features of the positioning of the operating upper limbs for novice and expert surgeons. These results may provide new insights into the efficacy of acquiring technical skills and reducing the burden on the body during laparoscopic surgery.

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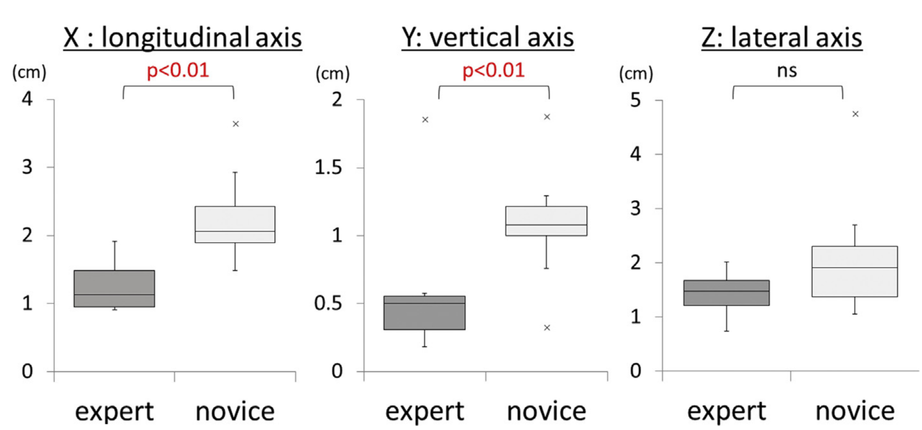

Fig. 3. Standard variability of the three axes of head movement range. The Mann–Whitney *U* test was used. A value of $p < 0.05$ indicated statistical significance.

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Author disclosures

Drs. Kenta Takayasu, Kenji Yoshida, Takao Mishima, Masato Watanabe, Tadashi Matsuda, and Hidefumi Kinoshita have no conflicts of interest or financial ties to disclose.

Conflict of interest

The authors have no conflicts of interest directly relevant to the content of this article.

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