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TECHNIQUES

Comparative assessment of surgeons' task performance and surgical ergonomics associated with conventional and modified flank positions: a simulation study

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Abstract

Background Flank position is extensively used in retroperitoneoscopic urological practice. Most surgeons follow the patients' position in open approaches. However, surgical ergonomics of the conventional position in the retroperitoneoscopic surgery is poor. We introduce a modified position and evaluated task performance and surgical ergonomics of both positions with simulated surgical tasks.

Methods Twenty-one novice surgeons were recruited to perform four tasks: bead transfer, ring transfer, continuous suturing, and cutting a circle. The conventional position was simulated by setting an endo-surgical simulator parallel to the long axis of a surgical desk. The modified position was simulated by rotating the simulator 30° with respect to the long axis of the desk. The outcome measurements include task performance measures, kinematic measures for body alignment, surface electromyography, relative loading between feet, and subjective ratings of fatigue.

Results We observed significant improvements in both task performance and surgical ergonomics parameters under the modified position. For all four tasks, subjects finished tasks faster with higher accuracy ($p < 0.005$ or < 0.001). For ergonomics part: (1) The angle between the upper body and the head was decreased by $7.4 \pm 1.7°$; (2) The EMG amplitude collected from shoulders and left lumber was significantly lower ($p < 0.05$); (3) Relative loading between feet was more balanced ($p < 0.001$); (4) Manual-action muscles and postural muscles are rated less fatiguing according to the questionnaire ($p < 0.05$).

Conclusions Conventional position of patient in retroperitoneoscopic upper urinary tract surgery is associated with poor surgical ergonomics. With a simulated surgery, we demonstrated that our modified position could significantly improve task performance and surgical ergonomics. Further studies are still warranted to validate these benefits for both patients and surgeons.

Keywords Flank position · Task performance · Surgical ergonomics · Retroperitoneoscopic

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Flank position is applied widely in retroperitoneoscopic upper urinary tract surgery because it offers good exposure of the renal parenchyma and upper ureter [1]. Besides advantage in surgery on the lower renal pole, ureteropelvic junction, and upper ureter, large amounts of laparoscopic partial nephrectomy, nephrectomy, and adrenalectomy are also conducted in this position in many Asian urological medical centers [2–5]. Most surgeons follow the patients' positions in open approaches in which patients are placed in a full-flank position and their upper bodies are parallel to the long axis of the operation bed [6]. However, in this

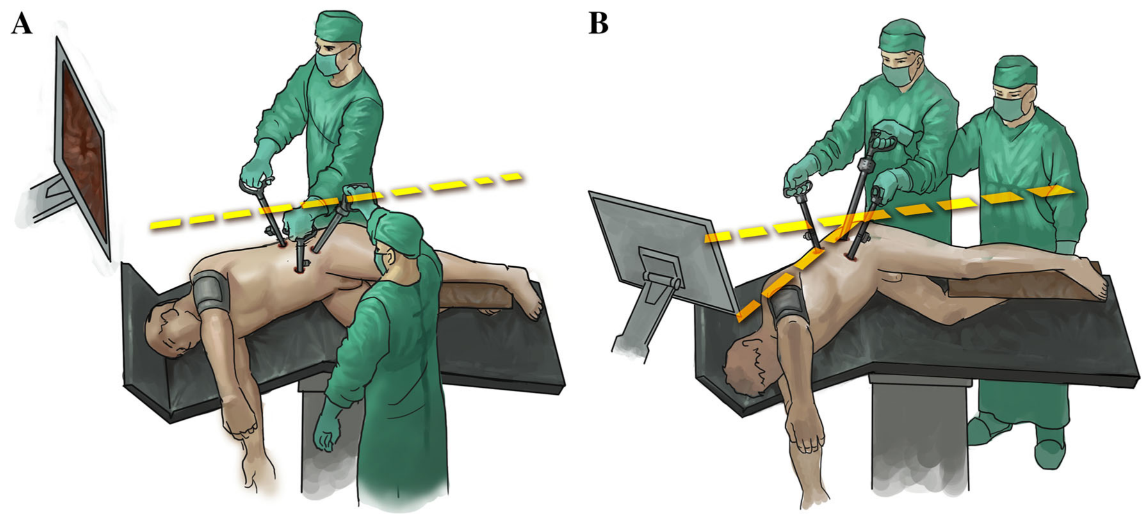

Fig. 1 Illustration of the conventional position (**A**) and the modified position (**B**) of a patient in retroperitoneoscopic upper urinary tract surgery

conventional position, the optical axis is often misaligned with the motor axis (Fig. 1A), forcing the surgeon to perform the operation with unbalanced posture and elevated muscular efforts. Previous studies indeed found that the deviation between the forearm–instrument motor axis and the optical axis can be extensive during retroperitoneoscopic operation [7]. This in turn makes the operation difficult and fatiguing, especially when the operation duration is long. After all, the surgeon's posture during retroperitoneoscopic operation is very static as compared during open surgery [8]. This can exacerbate musculoskeletal problems brought about by uncomfortable postures [9, 10].

According to surgical ergonomics principles, an operation environment should support good alignment of surgeons' motor axis, optical axis, and gravity center [11, 12]. Thus, we designed a modified patient position to overcome disadvantages of the conventional position during retroperitoneoscopic operation. Conventionally, the patient lays straight on his/her side, exposing the trunk's lateral side to the surgeon (Fig. 1A). For the modified position, instead of laying straight, the patient's upper body is rotated 20–30° forward (Fig. 1B) which depends on the height and weight of the patient. In this case, the upper body, as well as the motion axis, is aligned with the surgeon's optical axis. We believe that this position will support better motor coordination and offer the surgeon a more balanced posture to avoid fatigue, especially for novice trainers. To quantitatively investigate its benefits, we compared the conventional and modified positions in terms of task performance, postural kinematics, muscular activity, and kinetics in novice surgeons under a simulation environment.

Materials and methods

Participants

After institutional review board approval, 21 novice surgeons (premed students or first year surgical residents) were recruited to participate in this study. All of them were right-hand dominant. Experienced laparoscopic surgeons who had adapted to a certain work posture were excluded from this study.

Instruments and set-up

An endosurgical training system was used in our simulated operation experiments [13]. The system included a Sony 15" color monitor placed on a 51" mobile instrument tower approximately below the shoulder level of a standing participant (Fig. 2). The tower was fixed left adjacent to an operation desk. The screen of the monitor faced directly to the subject. The angle between the screen and the desk was 60°. A RuiHong® L-200U operation simulator with 0° video camera was placed on the desk and utilized for all tasks. In the conventional position, the simulator was placed parallel to the long axis of the desk. In the modified position set, it was placed 30° anti-clockwise (simulated the left flank position) from the desk's long axis, aligned with the monitor.

The body motion was measured throughout the experiment by an infrared motion capture system (OptiTrack, model V100, Natural Point Inc.). A rigid-body marker set was fixed behind the middle of the occipital bone to measure the head motion while a second marker set at the second vertebra thoracalis (xiphoid level) to measure the

Fig. 2 The simulation set of conventional position (**A**) and modified position (**B**). Relative locations of the simulator and surgical bed were illustrated in thumbnails, respectively. Traceable infrared rigid body markers (*orange*) were used to measure the orientation of the head and the upper body. Wireless EMG sensors were attached on shoulders and lumbers (*red*). Two Wii Fit balance boards were used to measure loading force of each foot (Color figure online)

upper body motion (Fig. 2) [14–16]. The angle between optical axis and motor axis is defined as the relative angle between the head and the upper body. The sampling rate was set at 100 Hz.

We also measured surface electromyography (sEMG) signals from bilateral shoulders (middle deltoids) and bilateral lumbar (erector spine, 2–4 cm lateral to the 4th lumbar segments) by using four separate wireless sensors (Trigno, Delsys Inc.) [17]. Signals were sampled at 1000 Hz and transmitted to a computer by an A/D card (NI USB-6009). The raw EMG signals were processed offline by rectification. The amplitude in muscle EMG was quantified as root mean square (RMS) over time and it is an indicator of muscle fatigue/strain· [18].

As two examined postures might involve different levels of symmetry in body balance, we measured the loading force underneath each foot by using two separate force plates (Wii Fit balance boards, Nintendo Inc.) [19]. The force was registered at 100 Hz continuously during the task, and the load ratio between feet (left vs. right) was calculated.

A fatigue questionnaire [20] was filled and collected after each task. Subjects were asked to rate their fatigue level by subjective scores ranging from zero (totally relaxed) to five (most fatiguing). The bilateral necks, shoulders, arms, lumbers, and legs were rated separately in the questionnaire.

All measurements were performed by a single customized Matlab program (Mathworks, version 2009a). We also used customized Matlab programs for data analysis.

Task and experimental design

Each participant was asked to finish four sessions of trials, two with conventional position and two with modified position. The order of sessions was randomized [21] (Table 1). Every session had 4 tasks [22]: (1) Bead transfer, the performance measure was the numbers of bead transferred and dropped within 3 min; (2) Ring transfer, the performance measure was the execution time for transferring 10 rings and the number of dropped rings; (3) Continuous suturing, the performance measure was the execution time for continuous suturing twice. This included the time for suturing twice and placing the suture under laparoscopic once; (4) Cutting one cycle: the performance measure was the execution time for cutting a cycle from a plastic paper with a marked cycle trace. Subjects first familiarized themselves about the tasks to be performed for

Table 1 The randomization matrix of the sequence of experimental sessions

All possible sequences	Session sequence							
		1		2		3		4
1	15-min	M	5-min	M	5-min	C	5-min	C
2	Warm up	M	Rest	C	Rest	M	Rest	C
3		M		C		C		M
4		C		C		M		M
5		C		M		C		M
6		C		M		M		C

C conventional position, *M* modified position

15 min before formal data collection. There was a mandatory rest of 5 min between sessions. The whole experiment lasted about 60–90 min.

Statistical analysis

The task performance measures were analyzed either by paired *t* tests or nonparametric Wilcoxon test, depending on the format of the data. For biomechanical and EMG variables, we averaged all independent measures over four tasks before further processing as we were only interested in difference between positions. The variables were analyzed using paired *t* test. The questionnaire data were analyzed using nonparametric Wilcoxon test. The statistical significance level was set at $\alpha = 0.05$.

Results

We describe the results in the following five categories: (1) task performance; (2) body alignment; (3) electromyography; (4) load ratio between feet; and (5) fatigue questionnaire.

Task performance

Performance measures were quantified for comparisons between two position conditions (Fig. 3). For bead transfer, the number of transferred beads within 3 min was significantly larger in the modified position than in the conventional position (14.0 ± 1.0 vs 10.7 ± 0.6; $p < 0.005$,

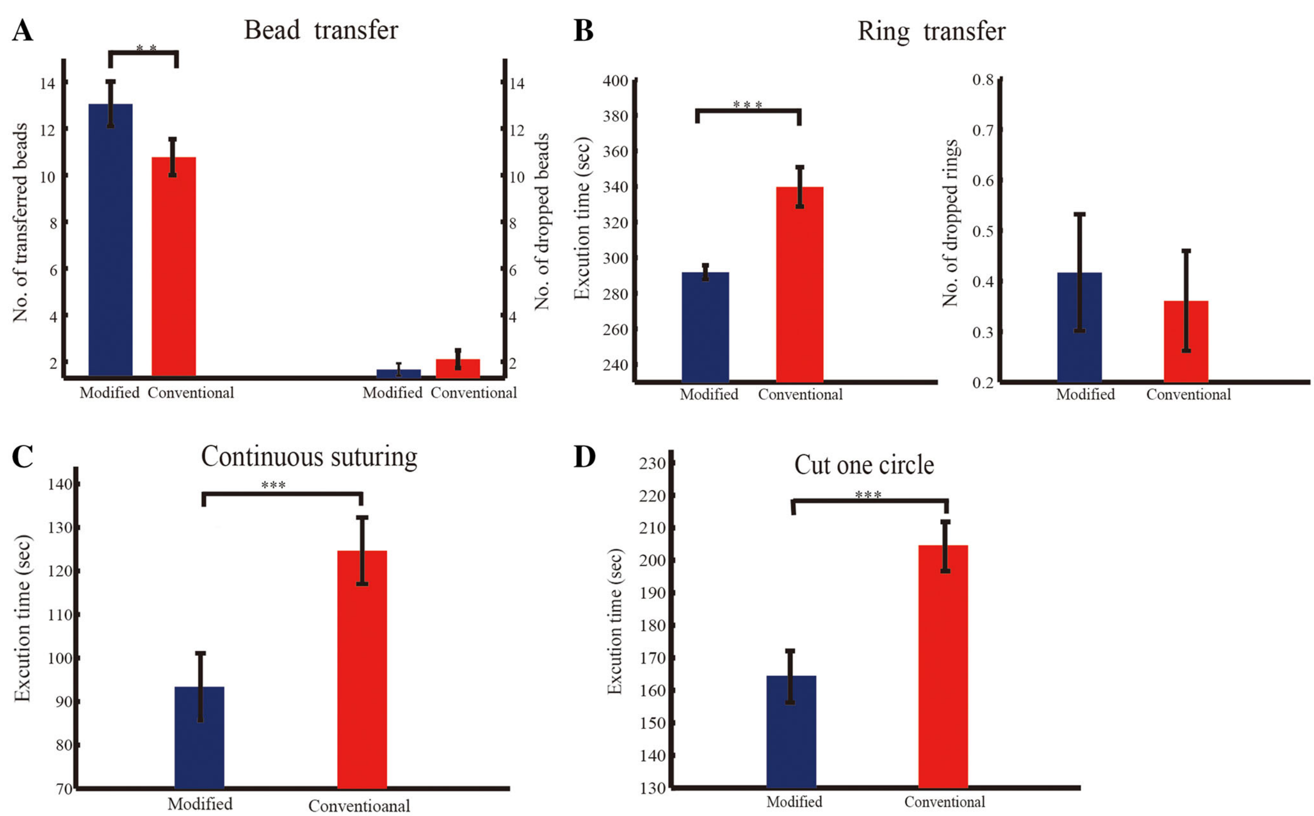

Fig. 3 Task performance for four tasks. **A** Bead transfer: the number of transferred beads is significantly larger for the modified position. The number of dropped beads is not significantly different across conditions. **B** Ring transfer: the execution time is significantly less for the modified position than for the conventional position; the numbers of dropped rings are similar between two conditions. **C** Continuous suturing: the modified position requires significantly less execution time than the conventional position. **D** Cut a circle: the execution time is significantly less for the modified position. ** and *** stand for $p < 0.005$ and $p < 0.001$, respectively

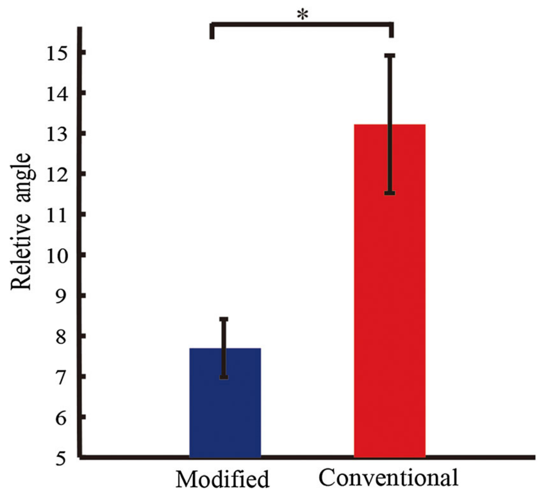

Fig. 4 Average relative angle between the head and the upper body in the conventional and modified conditions. The modified position yielded significantly smaller relative angle than the conventional position ($p < 0.05$)

Wilcoxon test). However, the number of dropped beads was similar for these two conditions (1.8 ± 0.2 versus 2.2 ± 0.3; $p = 0.98$, Wilcoxon test), possible due to the fact that most subjects usually dropped one or two beads over the whole experiment. For ring transfer, the execution time for transferring 10 rings was reduced in the modified position and the difference was extremely significant (259.7 ± 7.6 s and 319.9 ± 13.0 s, $p < 0.001$, paired t test). The number of dropped rings was similar between two conditions (0.40 ± 0.10 versus 0.3 ± 0.1, Wilcoxon test, $p = 0.623$). For continuous suturing, the modified position showed an advantage over the conventional position in terms of execution time (87.1 ± 5.9 s and 117.4 ± 6.7 s, respectively; $p < 0.001$, paired t test). For cutting one circle, the modified position also required significantly less execution time than the conventional position (166.3 ± 5.4 s and 206.4 ± 5.9 s, respectively; $p < 0.001$, paired t test). In sum, all 4 tasks showed performance improvement with the modified position (Fig. 4).

Body alignment

Conventional position leads to a misalignment between the head and the upper body while the modified position helps to align these two. The relative angle between the head and the upper body quantifies this body alignment. The larger the angle, the more uncomfortable and unbalanced the subject is. We found that this relative angle was significantly smaller in the modified position than in the conventional position (5.8 ± 0.5° vs 13.2 ± 1.7°, respectively; $p < 0.001$). The reduction in angle was as large as 7.4 ± 1.7°.

Electromyography

The RMS of EMG is an indicator of average muscle activity for the period of tasks. The greater the RMS is the easier for the subject to fatigue [23]. It was apparent that sEMG activity was more pronounced in the conventional position by visually inspecting the rectified raw EMG signals (Fig. 5A, left lumber in continuous suturing task).

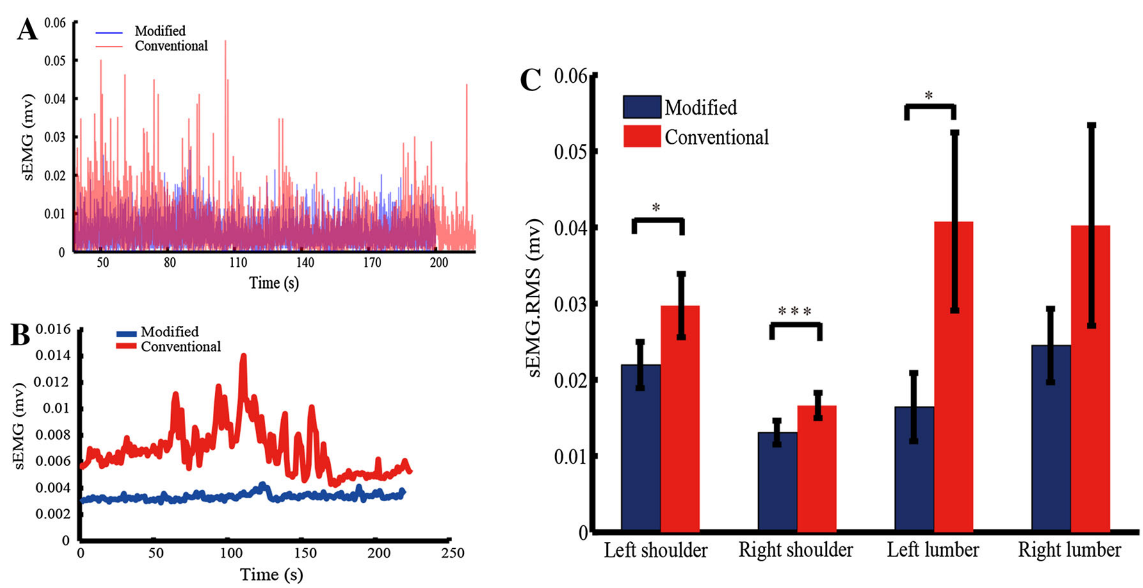

Fig. 5 EMG activities. **A** The rectified EMG signal, data from measurements on left lumber during a typical trial in continuous suturing task. **B** the RMS calculated over each 1,000 ms, data from the same trial shown **A**. **C** the mean RMS, plotted for left shoulder, right shoulder, left lumber, and right lumber separately. The modified position yielded significantly smaller RMS than the conventional position for left shoulder ($p < 0.05$), right shoulder ($p < 0.001$), and left lumber ($p < 0.05$)

This effect was also apparent with RMS measure (Fig. 5B). Note that subjects performed active movements caused the fluctuations in RMS. We further quantified the mean EMG activation of four muscles (left shoulder, right shoulder, left lumber, right lumber) by calculating RMS over the whole experiment (Fig. 5C). We found that the EMG activity was significantly more pronounced for the conventional position, as compared to the modified position, in both shoulders and left lumber (for left shoulder and left lumber, $p < 0.05$; for right shoulder, $p < 0.001$). There was an increasing trend in right lumber but the difference did not reach significance ($p = 0.234$).

Load ratio between feet

The postural imbalance is quantified by load ratio between feet, with a ratio of 1 indicating perfect symmetrical loading between feet. We found that the load ratio in the modified position is close to 1 (Fig. 6). In contrast, the load ratio in the conventional position is as large as 3.2 ± 1.7, indicating that subjects load substantially more on the left foot. The difference between these two conditions is highly significant (t (20) = −6.0 $p < 0.001$).

Fatigue questionnaire

Subjects rated their fatigue after task completion. The higher the score the more fatiguing subjects felt. Generally speaking, the score was lower in the modified position than in the conventional condition for all the rated body parts. Participants felt significantly less fatigued in the modified position for manual-activity related body parts including right neck, left shoulder, and left arm reach. Some postural muscles (bilateral lumbers) and left leg had significantly lower fatigue scores in the modified position. For the left versus right comparisons, participants also reported that the left leg and arm were more fatiguing than the right leg and arm ($p < 0.001$ and $p < 0.05$, respectively). No other left and right difference was found.

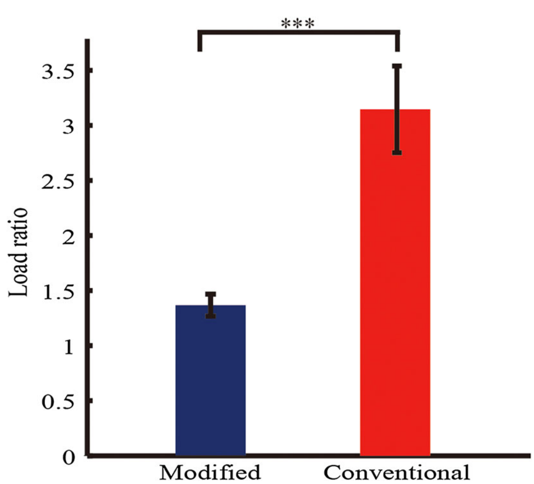

Fig. 6 Load ratio between left and right foot. The modified position is associated with more balanced load ratio (close to 1), which is significantly less than the one yielded by the conventional position ($p < 0.001$)

Discussion

In recent years, ergonomics in the operating room has been extensively investigated, with majority of studies focusing on room setting and instruments design [24–28]. This is a first study focusing on the improvements from modifying the patient's position. With simulated retroperitoneoscopic upper urinary tract surgery, we found that modifying the patient's position can greatly improve task performance and the surgeon's comfort. Across the four simulated operation tasks, novice surgeons showed significantly improvement in performance, such as reduction in task execution time and increase in effectiveness. Biomechanical analyses revealed better alignment between optical axis and motor axis and more balanced foot loading (and thus more balanced standing posture) during simulated surgery. Selective postural muscles (deltoid and erector spine) showed significantly less sEMG activities with the modified position. As a result, subjects also gave subjective report that the modified position was associated with less fatigue in most muscles we questioned. Overall, these objective and subjective results suggest that the modified patient position provides better ergonomics that leads to improved performance and better resistance to fatigue.

The conventional position for upper urinary tract surgery originates from the open surgery. Surgeons face the long axis of the patient with well-aligned optical axis, motor axis, and gravity center. However, in the retroperitoneoscopic setting, the same patient position does not meet the ergonomics principle. The optical axis deviates from the motor axis, forcing postural muscles activated continuously to support postural balance and making the eye–hand coordination more difficult. Furthermore, the gravity center is off the motor axis. Much of the weight loading is on one-side, which means the surgeon is poorly balanced and easy to feel fatigued. Indeed, we found that the conventional position is associated with substantial asymmetry in foot loading and in subjective level of fatigue: the load ratio between left and right foot is up to 3:1; participants rated the left side (leg and arm) more fatiguing than the right side. This is understandable given the operation has to be performed on the left side with this misaligned posture.

To overcome these disadvantages of conventional position in the retroperitoneoscopic setting, we proposed a modified position to re-align optical axis and motor axis.

To avoid confounding effect from experience and adaptation, we selected novice surgeons instead of experienced surgeons as participants [29]. We used randomized cross design to rule out the learning effect of the task itself. As our modification of the posture focused on the upper body alignment with the optical axis, we used a motion capture system to measure the relative angle between the head and the upper body. We hypothesized that this modified position would mostly improve postural symmetry and relieve related muscles, which could be revealed by measuring force loading underneath each foot and sEMG for selected muscles. Finally, we required subjects to give a subjective report of their fatigue in separate muscle groups.

With the modified position, we observed an approximately 10° reduction in relative angle between the optical axis and the motor axis. This better alignment made the screen more straight ahead of the surgeon, and more aligned with his/her forearm-instrument workspace. Accordingly, postural symmetry, as quantified by loading ratio between feet, was also significantly improved. It has been shown before that both speed and accuracy in short-duration tasks can be influenced by the alignment between the optical axis and the motor axis [30]. Indeed, participants significantly improved their task performance in all four tasks examined. We postulate that the ergonomic improvements by the modified position are mostly related to improved postural symmetry, and this in turn supports a better hands–eyes-coordination and improves the surgeon's performance in terms of efficiency and effectiveness.

Previous studies showed that the fatigue level of arms and shoulders is closely related to the task performance [31–33]. Our questionnaire results demonstrated that with the modified position participants felt less fatigued for most muscle groups. This subjective result was backed up by sEMG results: the muscles responsible for manual actions (deltoid) and postural control (erector spine) show significantly less activity with the modified position. We believe that these fatigue-related improvements also contribute to performance improvements we observed [34]. Over a long run, we believe that these improvements can help surgeons to avoid muscle strain and work-related injuries such as neck pain and low back pain [35–37].

The present study only involves simulated retroperitoneoscopic surgery with tasks of short durations. Previous study has demonstrated that fatigue level and EMG amplitudes increase over time in long-duration surgeries [10]. We thus postulate that the imbalance problem in the conventional position can lead to more severe muscle strain. As a result, the improvement brought by the modified position can be more pronounced in actual situations with prolonged clinical practices.

Given the scope of this pilot project, we have not performed a right-side simulation study though we expect similar results. We also propose that before this improved position can be applied to clinical practice, we should thoroughly evaluate patients' safety and comfort.

Conclusion

Conventional positioning of patient in retroperitoneoscopic upper urinary tract surgery is associated with poor body alignment and asymmetrical posture in surgeons. We demonstrated with simulated surgery tasks that a modified position, by rotating patient's upper body by 30 degrees forward, could significantly improve task performance and surgical ergonomics. The benefits for surgeons include improvements in task performance, body alignment, muscular activities, postural symmetry as well as ratings of fatigue. Further studies are still warranted to validate these benefits for both patients and surgeons.

Disclosures Dr. Yu Fan, Gaiqing Kong, Yisen Meng, Shutao Tan, Prof. Kunlin Wei, Qian Zhang, and Jie Jin and have no conflicts of interest or financial ties to disclose.

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