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Technical Report

Assessment of the Ergonomically Optimal Operating Surface Height for Laparoscopic Surgery

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ABSTRACT

Purpose: **The aim of this study was to find the ergonomically optimal operating surface height for laparoscopic surgery in order to reduce discomfort in the upper extremities of the operators and the assistants. The operating surface height was defined as the level of the abdominal wall of a patient with pneumoperitoneum.**

Materials and Methods: **Two pelvi-trainer tests were performed. One test was performed on six different operating surface heights. The (extreme) joint excursions of the shoulder, elbow, and wrist were measured by a video analysis method. Another test was performed by holding a laparoscope for 15 minutes while an electromyelograph of the biceps brachii was made. The results of both tests were evaluated subjectively by a questionnaire.**

Results: **The ergonomically optimal operating surface height lies between a factor 0.7 and 0.8 of the elbow height of the operator/assistant. At this height, the joint excursions stay in the neutral zone for more than 90% of the total manipulation time, and the activity of the biceps brachii when holding the laparoscope stays within 15% of the maximum muscle activity.**

Conclusions: **The operating surface height influences the (extreme) upper joint excursions of the surgeon. The ergonomically optimal operating surface height reduces the discomfort in the shoulders, back, and wrists of the surgeon during laparoscopic surgery. This optimal table height range for laparoscopic surgery is lower than those currently available.**

INTRODUCTION

IN THE LITERATURE, laparoscopic surgery is in many cases associated with ergonomic problems.[1–3] Surgeon complaints of fatigue and discomfort during laparoscopy have led to several studies that investigate the origin of these physical problems.[4–8] In one study, a comparison of the surgeon's posture during laparoscopic and open surgical procedures was made.[5] The main results of this study were a more upright head and back posture and less body movements (static postural stress) during laparoscopy. Also, the pressure on the shoulder and upper extremity muscles was found to be higher during laparoscopy. In other studies, it was shown that laparoscopic

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TABLE 1. NEUTRAL ZONES OF JOINT EXCURSIONS

Joint	*Movement*	*Neutral zone (°)*
Shoulder	Abduction	<30
	Adduction	<30
Elbow	Flexion	>30 <130
	Extension	0
Wrist	Ulnar abduction	<15
	Radial abduction	<15
	Palmer flexion	<15
	Dorsal flexion	<15

instruments cause excessive flexion and ulnar deviation of the surgeon's wrist and abduction of the surgeon's arms during manipulation.[1,4,6–9] The reason for these ergonomic problems is the combined effects of the fixed point of insertion of the laparoscope through the body wall, a large external arc of arm movement because of the greater length of the instruments, the ringed pistol type of instrument handles that are used, and poorly adjusted operating table height.[2] The results of these studies led to newly designed ergonomic handheld instruments.[6,9] Although some of these new instrument handles have improved the usability significantly,[9] the problem of excessive excursions of the upper extremities attributable to the incorrect operating table height still exists.

The importance and contribution of ergonomics to the design of workplaces has been recognized for decennia in other disciplines such as the military, aviation, and industry. Guidelines for the height of work surfaces for standing workers in industry or offices who are performing precision, light, or heavy work have existed for more than 20 years.[10] However, in the medical literature, only recently has a paper been published dealing with the ergonomic problem of incorrect operating table heights during laparoscopy.[11] In this study, the ergonomically optimal operating table height was assessed in a simulated model. Subjects of different stature used laparoscopic instruments with four different handle designs. The instruments were inserted into a board at three different angles, and the elbow angles of the volunteers were fixed to either 90° or 120°. For every variable, the height of the board, as a parameter for the level of the abdominal wall of a patient with pneumoperitoneum, was measured from the floor. No video analyses of the upper limb excursions or electromyelographic (EMG) measurements during simulated laparoscopic manipulations were done. In the study described here, the extreme upper limb excursions of subjects were measured for different operating table heights, and an EMG measurement was performed. These measurements were applied not only to the operator, who manipulates the instruments, but also to the assistant, who holds the laparoscope. The aim of this study was to find the ergonomically optimal operating surface height for laparoscopic surgery in order to prevent extreme upper limb excursions of the operator and the assistant. The results of this study can be used as a guideline for designers of operating room tables as well as for surgeons and other operating room personnel.

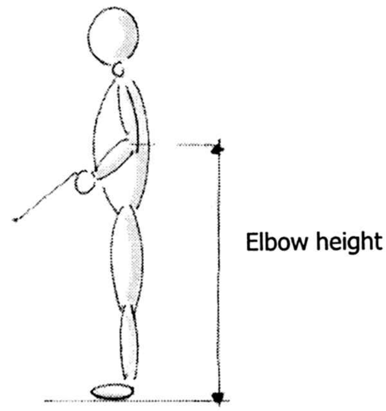

FIG. 1. Optimal posture of surgeon during laparoscopic surgery.

MATERIALS AND METHODS

Two studies were performed: an assessment of the optimal operating surface height during manipulation of the instruments (dynamic) and an assessment of the optimal operating surface height whilst holding the camera and laparoscope during surgery (static). To prevent extreme joint excursions, the comfortable positioning possibilities of the upper extremities and the range of movement of the diverse joints had to be identified. Different data found for the range of movements of joints were analyzed.[12–14] In Table 1, one can find the neutral zone for this study's most important joints of the upper extremities. The posture in Figure 1 is considered optimal for the laparoscopic surgeon.[6] In this posture, the arms are slightly abducted, retroverted, and rotated inward at shoulder level. The elbows are bent at about 90° to 120°, the wrists are slightly extended, and the hand is completely relaxed.

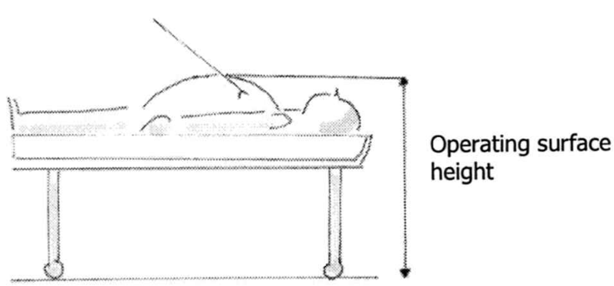

FIG. 2. Operating surface height is defined as level of abdominal wall of patient with pneumoperitoneum.

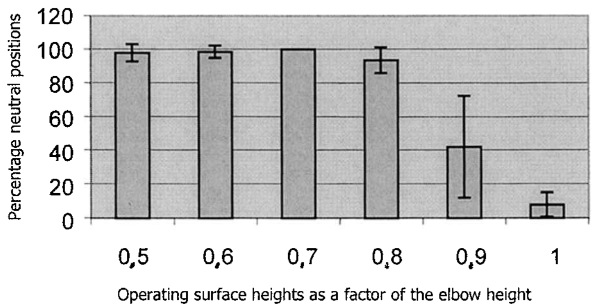

FIG. 3. Percentage of neutral abductions of shoulder.

First study (dynamic)

Task. The subjects had to perform a 5-minute precision task in a pelvi-trainer. The task consisted of picking up chips with dissection forceps with an angled ring handle and placing these chips over the pins of an object. The monitor was placed in front of the surgeon at a height of 160 cm (bottom monitor). The operating surface height was adjusted to six different positions (randomized for each subject): factors 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 of the elbow height of the surgeon in a standing position (Fig. 1). These relative elbow height factors were chosen to normalize the data in order to make it easier to adjust the table later to the right operating height. It is more likely that operating room personnel will remember the right elbow factor (this factor is the same for everyone) than an absolute table height (in centimeters) suitable for their body length.

The operating surface height was defined as the level of the abdominal wall of a patient with pneumoperitoneum (Fig. 2). This height differs for each patient. To cover the range of lengths of the different volunteers, the operating surface height must be able to adjust between 45 and 130 cm. After performing the test, the volunteers filled in a questionnaire.

Subjects. The surgeons and residents volunteering to perform the test reflected the user group. Eight volunteers with different levels of experience in laparoscopy ranging from 1 to 8 years performed the test. Two volunteers were female, and one was left-handed. The body length, shoulder height, and upper arm length of every subject were measured.

Video analyses. Two cameras were used to measure the positions of the hand and arm. One camera was positioned above the subject, the other in front of the subject at a 90° angle to the other. A special video recording system was used to put three camera images (two cameras and the endoscope) on one video frame. The video was stopped at 2-second intervals (range 30–270 seconds), and the angle of the joint (neutral or extreme; see Table 1) was rated. The amount of extreme positions was calculated as a percentage of the total amount of measured video frames (120).

Questionnaire. The subjects answered the following question for all six table heights after performing the experiment: Regarding the position of the body, especially the upper extremities, what is the experience of comfort/discomfort during the experiment? All six table heights had to be scored on a visual analog scale (VAS; length 100 mm), the two parameters being uncomfortable (0 mm) and comfortable (100 mm).

Additional study (static)

To make sure that the optimal posture resulting from the dynamic study can also be considered as the optimal posture for the assistant during laparoscopy, an additional study is needed. During laparoscopic surgery, the assistant continuously holds the laparoscope in the same position. Static muscle loading can cause fatigue and less muscle activity.[5] If the posture of the assistant is static for a long time, that posture has to be neutral. During a static activity, the biceps bracchii muscle has to be exerting less than 15% of the maximum force.[12]

Task. Eight volunteers held a camera and laparoscope in the pelvi-trainer for 15 minutes. The height of the table was adjusted to the body length of the subject in such a way that the body and arms were in a neutral position (see Fig. 1). The operating surface height was measured according to Figure 2. The operating surface height was defined as a factor of the measured elbow height.

Subjects. The same subjects who participated in the first test completed the second.

Analysis. Electrodes were placed on the main muscle for flexion: biceps brachii. An EMG was made of the maximum force of the biceps during flexion (sensitivity 1 mV/V; filter 20–2000 Hz, four channels). This maxi-

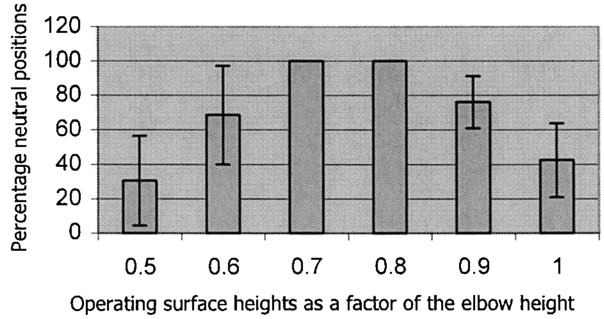

FIG. 4. Percentage of neutral flexions of elbow.

mum voluntary force was defined by asking the subject to lift a too-heavy table from the floor. An EMG of the biceps (sensitivity 200 μV/V, filter 20–2000 Hz, four channels) was made during the 15 minutes of camera holding. The mean of this EMG was compared with the maximum muscle activity of the biceps.

Questionnaire. The subjects answered the following question after performing the experiment: Regarding the position of the body, especially the upper extremities, what is the experience of comfort/discomfort during the experiment? The answer had to be scored on a VAS (length 100 mm), the two parameters being uncomfortable (0 mm) and comfortable (100 mm).

Hypothesis. To measure the differences between the different operating surface heights in relation to the tested parameters, the means of the results of both the questionnaire and video recordings were compared. Considering the above, the following hypotheses were made: For the video analyses, H0: the percentages of neutral positions of the shoulder are equal for all operating surface heights and H1: at least two of the means are not equal. For the second, H0: the percentages of neutral positions of the elbow are equal for all operating surface heights and H1: at least two of the means are not equal. For the third, H0: the percentage of neutral positions of the wrist are equal for all operating surface heights and H1: at least two of the means are not equal. For EMG analysis, H0: the mean of the EMG of the biceps is $\geq$15% of the maximum activity of the biceps (MMVC) and H1: the mean of the EMG of the biceps is $<$15% of the maximum activity of the biceps (MMVC). For the questionnaire, H0: for each question: the VAS scores are equal for all operating surface heights and H1: at least two of the means are not equal.

Statistical analysis. The data from both validation tests (subjective and objective) were analyzed with a nonparametric Wilcoxon signed-rank test using the software program SPSS 8.0. The statistical significance level was set at $\alpha = 0.05$.

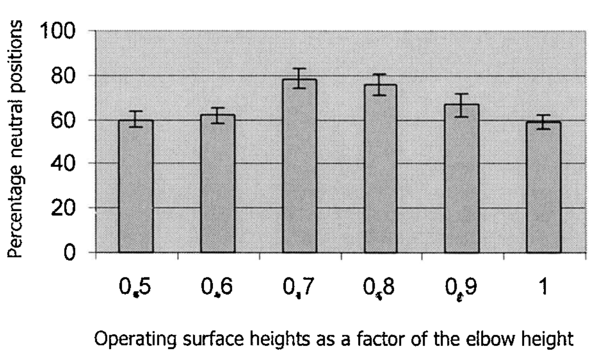

FIG. 5. Percentage of neutral positions of wrist.

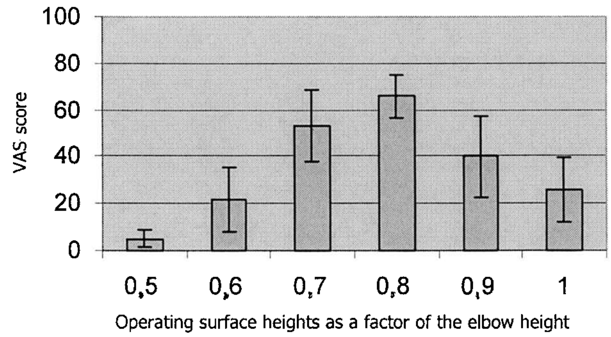

FIG. 6. VAS scores for six operating surface heights.

RESULTS

First study

The results of the video analysis of the shoulder are shown in Figure 3. When the height of the operating table was set at 0.5, 0.6, 0.7, or 0.8 of the elbow height, significantly more neutral shoulder positions were recorded than with the factors 0.9 and 1.0 ($P \leq 0.05$).

The results of the video analysis of the elbow are shown in Figure 4. Factors 0.7 and 0.8 of the elbow height scored significantly better than factor 0.5, 0.6, 0.9, and 1.0: more neutral elbow excursions were recorded ($P \leq 0.05$).

The results of the video analysis of the wrist are shown in Figure 5. When the height of the operating table was set at 0.7 or 0.8 of the subjects' elbow height, significantly more neutral wrist excursions were recorded than when the height was set on a factor of 0.5, 0.6, 0.9, or 1.0 of the elbow height ($P \leq 0.05$). The results of the video analysis showed that the optimal operating surface height for all joint excursions lay between 0.7 and 0.8 of the elbow height.

The results of the VAS score for the six operating table heights are shown in Figure 6. The subjects considered factor 0.6 of the elbow height significantly more comfortable than factor 0.5 ($P = 0.012$). Factor 0.7 was considered more comfortable than factors 0.5, 0.6, 0.9, and 1.0 (respectively, $P = 0.012$, $P = 0.036$, $P = 0.05$, and $P = 0.012$). Also, factor 0.8 scored significantly better than factors 0.5, 0.6, 0.7, 0.9, and 1.0 (respectively, $P = 0.012, P = 0.012, P = 0.017, P = 0.012,$ and $P = 0.018$). The results of the subjective evaluation fit the results of the objective assessment: the optimal operating surface height lies between 0.7 and 0.8 of the elbow height.

Additional study

In Table 2, the average and standard deviation of the factor of the elbow height and the results of the EMG scores are shown. These values were measured while the volunteer was holding the laparoscope in the ergonomi-

TABLE 2. AVERAGE FACTOR OF ELBOW HEIGHT AND EMG SCORES

Factor elbow height	
Mean	0.69
SD	0.01
Percentage EMG	
Mean	7.3
SD	2

cally optimal position. The muscle activity stayed below 15% of the maximum. The result of the VAS score on the question "Regarding the position of the body, especially the upper extremities, what is the experience of comfort/discomfort during the experiment?" was a mean of 64.3 (SD 20).

DISCUSSION

The height of the operating table influences the excursions of the upper extremities of the operator and the assistant during laparoscopy. In laparoscopy, the manipulations of the surgeon are limited by the fixed point of insertion of the endoscope through the body wall and the large external arc of movement attributable to the length of the laparoscopic instruments. This study was designed to assess the most ergonomically optimal operating surface height in laparoscopy. The study was separated into two parts, one for the operator (dynamic) and one for the assistant (static). The test was performed in a pelvi-trainer to create a standardized test environment. In the dynamic assessment, the subject had to manipulate laparoscopic instruments (dissection forceps with an angled ring handle), and in the static assessment, the subject had to hold the endoscope. The pelvi-trainer test is representative of manipulations in the dissection phase of an operation, and the instruments also are representative, as this type of handle is used by more than 85% of the laparoscopic surgeons.[7]

Although the number of the volunteers is small, we do not expect any bias. The results from this group are representative of the whole population because the group of volunteers was diverse: the volunteers were of both sexes, one volunteer was left-handed, they had different levels of experience, and they differed in body length, shoulder height, and upper arm length. The chance is small that extreme persons were selected. The results of the analyses are significant; these results would not change with more volunteers. Another point of discussion can be the technique used for the rating of extreme joint positions. Rating of joint excursions is a reliable and valid method to determine the position of joints (extreme–not extreme). We used this method in a prior study where the video stills were independently observed and examined by two persons, and both outcomes were within the 95% confidence interval.[8]

The results of the test show that the factors 0.7 and 0.8 of the elbow height score significantly better than the other factors in the video analyses (objective) as well as in the questionnaire (subjective). This indicates that the optimal operating surface height lies between the factor 0.7 and 0.8 of the elbow height. A lower operating surface height is not desirable because the back of the subjects was flexed 25°, and the subjects recorded back muscle pain. Also, the elbows are totally stretched, which restricts freedom in movement. A higher operating surface height is also not desirable because of abduction of the shoulder 30° and ulnar deviation of the wrists. A surface height of 0.9 and 1 caused discomfort in the wrists, shoulders, and necks of the subjects. When the surface was set at a height of a factor 0.7 and 0.8 of the elbows, more movements of the wrist were recorded, probably because of the more comfortable position of the arm and the hand. The volunteers experienced these operating surface heights as comfortable because they had more freedom in movement and experienced less discomfort in their shoulders, backs, and wrists.

To make sure this optimal posture can also be considered the optimal posture for the assistant during laparoscopy, the activity of the biceps brachii must stay within 15% of the maximum muscle activity. This was the case in all eight volunteers. Therefore, the optimal posture can also be considered as the optimal position for performing a static task (holding the laparoscope).

Considering the different elbow heights of the surgeons and the differences in the position of the patient during the operation, the range of the operating table heights for laparoscopic surgery must be between 29 cm (minimum) and 69 cm (maximum) (Table 3). The cur-

TABLE 3. RANGE OF HEIGHTS (CM) FOR ERGONOMICALLY OPTIMAL LAPAROSCOPY

	Minimum	*Maximum*
Surgeon		
P5, female, 0.7 × elbow height	65	—
P95, male, 0.8 × elbow height	—	100
Patient		
P95, male	—	36
P5, female	31	—
Operating table height	29	69

rent operating tables are designed for open surgery and have an average range of 55 cm (minimum) to 100 cm (maximum). To make sure the laparoscopic surgeon can adjust the operating surface height to the optimal work position, operating tables have to be redesigned or the surgeons have to use a foot-floor.

In this text, the height of the surface was adjusted to the elbow height of the subject. In practice, it is quite complicated to measure the elbow height of every surgeon in order to adjust the operating surface height to the proper length. In practice, the following guideline can be used: adjust the operating surface height to the pubic bone.

CONCLUSION

In this study, we showed that the operating surface height influences the (extreme) upper joint positions of the surgeon. Significant differences were found between the different operating surface heights. The ergonomically optimal surface height for laparoscopic surgeons and the assistants lies between 0.7 and 0.8 of the elbow height of the subject. With this operating surface height, the extreme upper joint positions are brought to a minimum, and the subjects experience less discomfort in their backs, shoulders, and wrists. The optimal operating table height is lower than the currently used tables can go.

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