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SURGICAL ENDOSCOPY
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Ergonomic aspects of five different types of laparoscopic instrument handles under dynamic conditions with respect to specific laparoscopic tasks: An electromyographic-based study

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Abstract
Background: The ergonomic deficiencies of various minimally invasive surgery (MIS) instrument handles are well-known. In the past, many studies have been performed to gain a better understanding of ergonomics in MIS. The current study investigates muscle strain during various dynamic tasks with different instrument handles.
Methods: Five different handle designs were tested: the axial handle (Aesculap), the vario handle (own model), multifunctional and ring handles (both Karl Storz), and the shank handle (Wilo). Ten subjects without any surgical training tested the following instrument functions: precise dynamic movement, rotation of the closed instrument, and simultaneous opening and closing of the effector. During these three trials, task performance (errors / duration) and the electromyographic activity of the hand and lower arm muscles were measured.
Results: Regarding the errors and the time required to carry out the tasks, the five handles showed similar results. The muscle activity was lowest for the precise dynamic movement task and highest during the rotation task. The axial handle required significantly more muscle activity than all other handles.
Conclusion: On the basis of these data, it was possible to construct characteristic muscle activation patterns for each handle. However, these patterns were not task specific. Accordingly, they may form a basis to improve the ergonomics of MIS handles with regard to muscle strain.

Key words: Laparoscopy — Surgical instruments — Ergonomics — Human factors — Electromyography

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It is well documented that hand–eye coordination during laparoscopic operations is impaired due to indirect vision via the monitor and the long-shafted instruments. Every surgeon knows that indirect manipulation of the instrument handles is complicated, and because of high friction inside the instruments it is nearly impossible to draw conclusions about tissue consistency. Therefore, ergonomic aspects of instrument handles are of enormous interest for surgery and should not be underestimated as discussed in previous papers [5, 13, 16, 21].

Surgeons, designers and engineers have been working toward standards to improve ergonomics of minimally invasive surgery (MIS) handles [9, 13, 15, 22]. For a comfortable working position of the upper extremities, it is important that the manipulation of the instruments requires a minimum amount of energy. Studies by Berguer et al. [1, 2], Emam et al. [5, 6], Quick et al. [17], and our own team [10, 11] using electromyographic (EMG) analysis showed that various handle designs impose different strain on lower arm and thenar muscles. Previous EMG-based studies have mainly investigated the opening and closing of the instruments under more or less static conditions. Important isolated movements such as rotation or precise guiding of an instrument have not been investigated. These three minimum dynamic functions can be carried out with any handle that is currently on the market. The current study, using phantom trials and EMG analysis, aims to answer the following questions: Which handle is particularly suited to which task? Can one particular handle carry out these three tasks equally well?

Materials and methods

In order to answer these questions, we investigated five different types of handles. Due to their different designs, these handles are grasped,

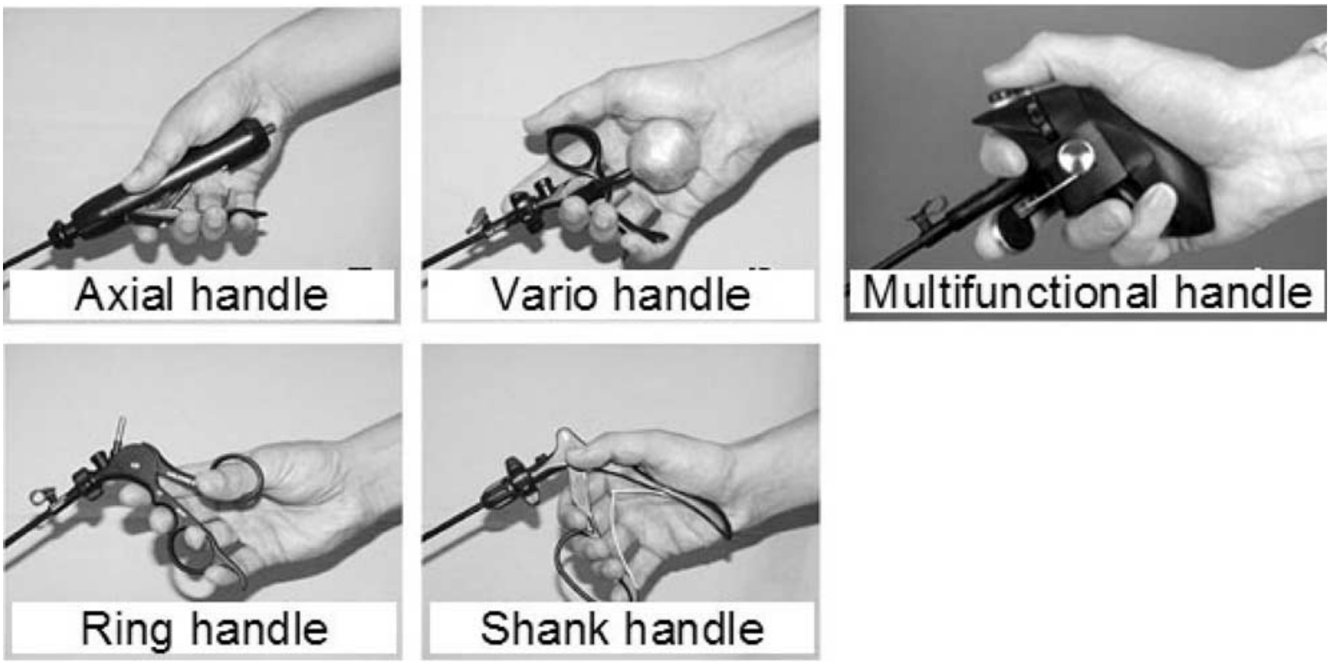

Fig. 1. Hand postures when holding and manipulating the five different handles: axial handle PM 953 R (Aesculap, Tuttlingen, Germany), vario handle (functional model, Study Group Surgical Technologies, Univ.-Hospital, Freiburg, Germany), multifunctional handle CE 33124 M (Karl Storz Endoskope, Tuttlingen, Germany), ring handle CE 33121 (Karl Storz Endoskope, Tuttlingen, Germany), and shank handle 25.00 (Wilo, Bühlertann, Germany).

Table 1. Characteristics of the five different types of instrument handles

Handle code	**A**	**V**	**M**	**R**	**S**
Handle design	Axial handle	Vario handle with ball and ring	Multifunctional handle	Ring handle	Shank handle with ring
Producer	Aesculap Germany	Study Group Surgical Technologies	Karl Storz Germany	Karl Storz Germany	Wilo Germany
Product No.	PM-953-R	None, prototype	CE 33124 M	CE 33121	25.00
Functional elements for opening/closing with/without spring	A lever for four fingers with spring	With a ring for the thumb	Key for middle finger with spring	Two loops for thumb and ring finger	Pistol principle with spring
Functional element to turn the effector	Not available	Cock wheel on the shaft for index finger	Cock wheel for thumb	Cock wheel on the shaft for index finger	Cock wheel on the shaft for index finger
Ratchet	Yes	No	Yes	No	Yes

held, and used in different ways. As has been discussed elsewhere, an instrument's handle influences the posture of the upper extremities [5, 9, 11–13]. Various grasping movements are necessary to carry out these functions. Hand postures while grasping the handles are shown in Fig. 1, and technical details of the handles are given in Table 1:

A: axial handle PM 953 R (Aesculap, Tuttlingen, Germany)
V: vario handle (functional model, Study Group Surgical Technologies, Univ.-Hospital, Freiburg, Germany)
M: multifunctional handle 33124 (Karl Storz Endoskope, Tuttlingen, Germany)
R: ring handle CE 33121 (Karl Storz Endoskope, Tuttlingen, Germany)
S: shank handle 25.00 (Wilo, Bühlertann, Germany)

Ten subjects with no surgical training carried out the experiments using the five instrument handles in randomized order. To investigate function-specific ergonomic qualities of the handles, each function (precise moving, rotation, and opening/closing) must be evaluated separately. Therefore, three test fields were set up in the format of the "hot wire" agility test and built on a synthetic surface (Uriol) measuring 120 × 120 mm (Fig. 2). Three specially formed curved wires, carrying 12 V, were mounted on this surface. These test fields were attached using Velcro fasteners to an inclined board secured to the wall of the Ergo Box (Fig. 3), as used in previous studies [10, 11]. The trocar was positioned at the height of the upper third of the thigh. This results in the recommended ergonomic posture for laparoscopic surgeons [8]. The surface of the test fields was inclined at an angle of 60° from the horizontal. In this way, it was possible to keep the instruments in a 60° working angle as suggested by Hanna et al. [7], and this has been used as a standard in several studies [1, 5, 10].

The following test courses were performed:

Test course 1, "*curve*" (Fig. 2): This experiment analyzes the precise movements of the instrument in a closed state. Pro- and supination are performed under dynamic conditions while simultaneously moving and holding a T-shaped, 2.7-g metal test object. For this purpose, an arched depression was cut into the test field's Uriol socket. Parallel to this, two wires ran along the sides and a third one just above the deepest point of the depression. The two side wires were approximately 20 mm apart and approximately 10 mm above the middle wire.

Test course 2, "*helix*" (Fig. 2): This experiment investigates the purely rotational movements. The test field consisted of two parallel arranged spiralling wires. The task was to twist a metal rod (weight, 10.8 g; length, 11.5 cm) into and out of the helix without touching the wires.

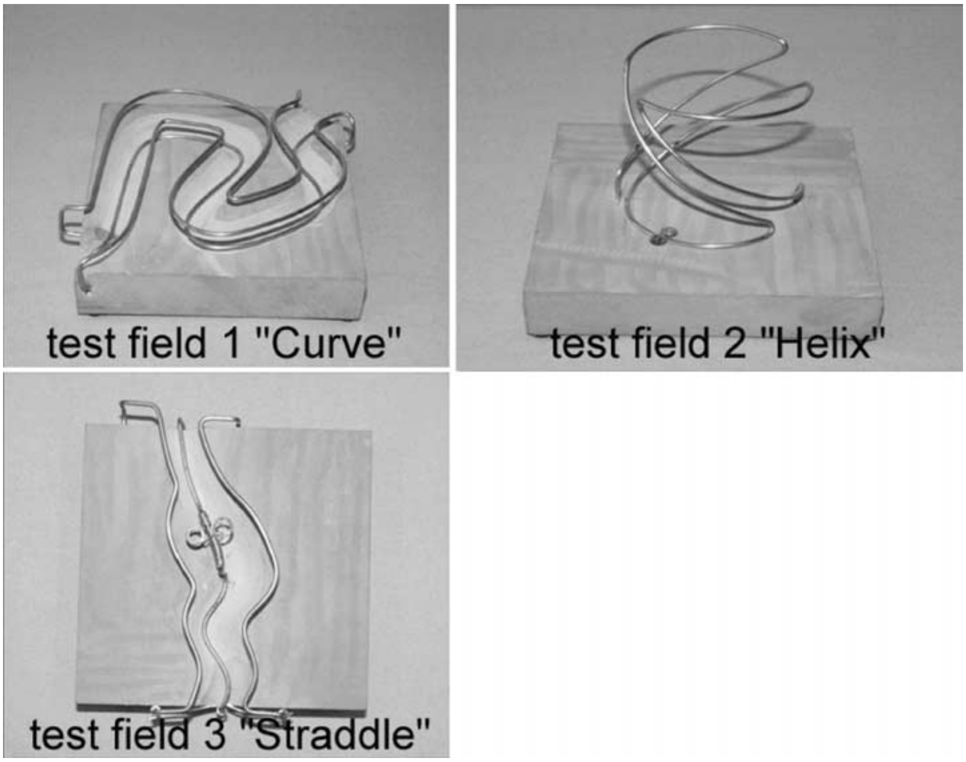

Fig. 2. The three test courses: 1, curve; 2, helix; and 3, straddle.

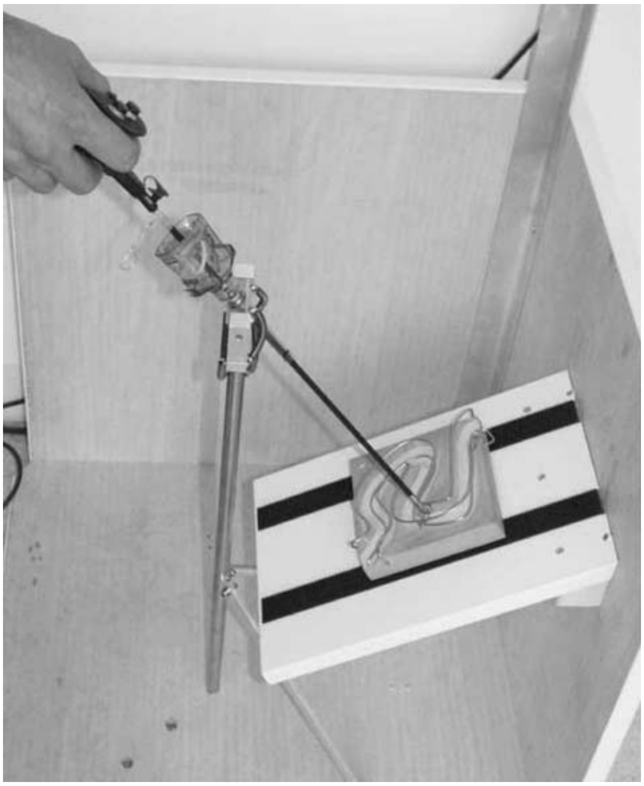

Fig. 3. The experimental setup: the instrument with the multifunctional handle is moved through a test course within the Ergo Box.

Test course 3, "*straddle*" (Fig. 2): This experiment requires a combination of precise guiding and opening / closing movements of the instrument. The test field consisted of three parallel wires, similar to test course 1. However, at one point the middle wire was raised (like an island) between the two outer wires. The instrument had to be opened at this point in order to guide the instrument through the course without touching one of the three wires. To make it more difficult, an additional object was fixed at the tip of the instrument. In this experiment, only the island area was evaluated, which allows the assessment of opening and closing procedures while guiding the instrument.

The sequence of handles used and of test courses was randomized in order to eliminate training effects. The test persons had to complete the courses within 15 sec without touching the wires. Any attempts to finish the course that took longer than 15 sec were not considered in this assessment. Each subject performed the trial five times. Errors were classified as follows:

- Dropping a test object: This could relate to a lost needle or gallstone. This mistake was only recorded in test courses. 1 and 2 because in test course 3 the test object was attached to the instrument.
- Touching a wire: This was signaled to the subjects by a light-bulb and recorded by the computer. This corresponds to a contact with an organ, for example, by an electric hook or the tip of a needle. Intraoperatively, this could lead to complications.
- Contact duration: The sum of periods of such touching errors was also registered and expressed in percentage of the entire trial time. This percentage corresponds to the total organ contact time during a real laparoscopic procedure. The higher the percentage, the higher the risk of severe complications.
- The video of the whole experiment and the EMG-data were recorded synchronised on computer hard disk. Using the video clip the exact "trial time" was measured. This trial time is relevant for the percentage calculation of contact errors.

Electromyography

The comparison of EMG activity in different muscles provides information about the force developed by each muscle and allows the assessment of its contribution to a functional movement. EMGs of the following forearm and hand muscles were recorded as described in detail in previous studies [10, 11]: thenar muscle (TH), M. extensor digitorum communis (EDC), M. flexor digitorum superficialis (FDS), M. flexor carpi radialis (FCR), and M. flexor carpi ulnaris (FCU).

Table 2. Mean value of the trial time, number and time of contact errors, and number of dropped test objects shown separately and as a total for the five handles and three test courses ($n = 10$)[a]

	A	V	M	R	S
Trial time (sec)					
Curved	**11.59** (*1. 49*)	**12.14** (*1.63*)	**12.5** (*1.32*)	**12.21** (*1.42*)	**12.29** (*1.33*)
Helix	**10.82** (*2.08*)	**10.39** (*1.86*)	**10.9** (*1.93*)	**11.28** (*1.65*)	**10.68** (*2.06*)
Straddle	**8.82** (*2.15*)	**9** (*2.07*)	**9.22** (*2.35*)	**8.68** (*2.2*)	**9.74** (*1.65*)
Total	**10.36** (*1.61*)	**10.22** (*1.47*)	**10.74** (*1.58*)	**10.61** (*1.14*)	**10.76** (*1.31*)
No. of contact errors					
Curved	**6.49** (*1.27*)	**7.26** (*2.2*)	**7.34** (*1.61*)	**6.81** (*2*)	**5.92** (*1.06*)
Helix	**4.22** (*1.2*)	**4.15** (*1.1*)	**4.3** (*0.93*)	**4.72** (*0.94*)	**4.44** (*1*)
Straddle	**2.68** (*0.84*)	**2.37** (*0.62*)	**2.88** (*1.43*)	**2.68** (*1.3*)	**3.11** (*0.9*)
Total	**4.43** (*0.54*)	**4.21** (*0.83*)	**4.66** (*0.86*)	**4.6** (*0.86*)	**4.69** (*0.71*)
Time of contact errors (sec)					
Curved	**3.82** (*1.21*)	**4.35** (*2.02*)	**4.32** (*2.1*)	**3.77** (*2.16*)	**3.82** (*1.83*)
% of the trial time	32.9	35.8	34.5	30.9	31.1
Helix	**4.03** (*1.56*)	**4** (**1.87**)	**3.76** (*1.8*)	**4.74** (*1.9*)	**4.33** (*1.31*)
% of the trial time	37.2	38.5	34.5	42	40.5
Straddle	**1.32** (*0.71*)	**1.26** (*1.08*)	**1.58** (*1.18*)	**1.24** (*0.8*)	**1.91** (*1.12*)
% of the trial time	14.9	12.9	17.1	14.3	19.6
Total	**3.04** (*0.96*)	**3** (*1.51*)	**3.12** (*1.54*)	**3.2** (*1.23*)	**3.24** (*1.15*)
No. of dropped test objects					
Curved	—	**7**	—	—	—
Helix	**2**	**1**	**1**	—	—
Total	**2**	**8**	**1**	—	—

[a] Standard deviations shown in parentheses

EMG activity was recorded by bipolar surface electrodes (diameter, 9 mm) placed 2 cm apart above the muscle bellies. The signals were amplified and transferred online to a computer system via an analogue–digital converter sampling at 500 Hz. The data were analyzed offline with software programmed in LabView (National Instruments, Munich, Germany). EMG activity was quantified using the root mean square (RMS) values of the EMG signal. The RMS values allow a quantitative comparison of muscle activity [4, 18] and thus, indirectly, the muscle force required for each handle. Mean values were calculated from consecutive tests. At the beginning and at the end of the complete series maximum voluntary EMG activity was assessed by pressing a tennis ball for 10 sec with maximum force. For better interindividual comparability, the EMG values of the tests for each muscle were expressed as a percentage of this maximal voluntary EMG activity of the respective muscle.

Statistical evaluation

Calculations were performed with a spreadsheet program (MS-Excel). The final data were transferred to SPSS software for statistical analysis. The parameters trial time, number and time of contact errors, number of dropped objects, and EMG activity of the five muscles were tested using the parametric Friedman test in order to compare several independent random tests for significant statistical differences ($p < 0.05$). Only after the Friedman test was it possible to detect significant statistical differences in the distribution of the variables involved. Then, supplementary comparisons (in pairs) using the Wilcoxon test were carried out. Each criterion was examined for differences between handles and test courses.

Results

Trial time

There was no statistically significant difference between the five handles or the three test courses. Thus, regarding time, no handle is superior to the others. Detailed data are given in Table 2.

Number of contact errors

The number of contacts between instruments or test objects and the wires on the test courses was approximately the same for all five instrument handles. Most contact errors occurred on the curved test (course 1). The lowest number of contacts occurred on the straddle test course 3 (Table 2).

Time of contact errors

Measuring the contact periods with the wires, no substantial differences were found between the handles. The contact time was lowest on the straddle test (course 3) and approximately 2 sec for all handles. This covers between 12.9% (handle V) and 19.6% (handle W) of the total course duration. The longest contact times measured were for guiding and turning the instrument in the helix test (course 2). These ranged from 34.5% (handle M) to 42% (handle R). All handles used to guide the fixed test object in the curved test (course 1) displayed a contact error rate of approximately one third of the total trial time (Table 2).

Number of dropped test objects

In order to test the function of opening/closing in the straddle test (course 3), the test object was fixed to the instrument and, therefore, could not be dropped. While guiding the instrument through the curved test (course 1) with handle V, half of the subjects dropped test objects. This occurred only at the beginning of the trial. After some practice, the subjects no longer dropped test objects. On the helix test (course 2), there were no significant differences between the individual handles because only a few test objects were dropped while using

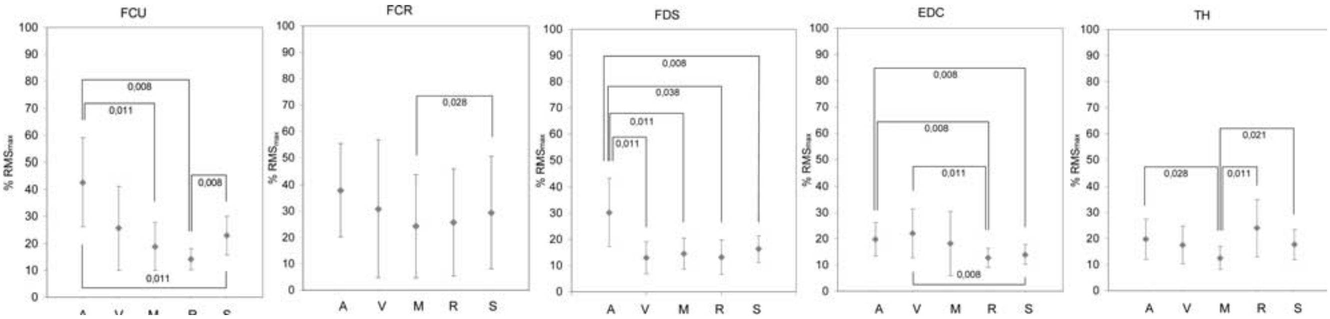

Fig. 4. Comparison of the relative EMG activities (% RMS_{max}) of the five muscle groups while guiding the instrument through test course 1, curve. The vertical bars indicate the 95% confidence interval. p values are given where differences were statistically significant. FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle.

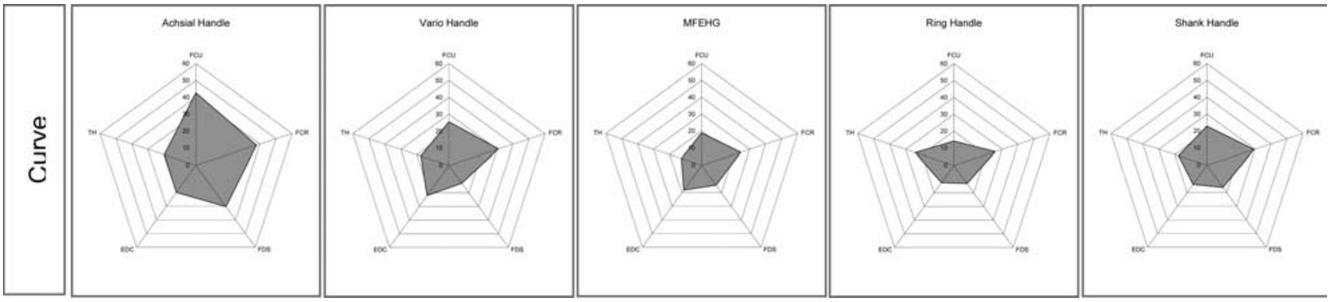

Fig. 5. Web diagrams comparing the relative EMG activities (% RMS_{max}) of the five muscles while using each handle to guide the instrument through test course 1, curve ($n = 9$).

handles A, V, and M. Regarding the number of dropped test objects from the test courses 1 and 2, it is obvious that more were dropped using handle V than with any other handle (Table 2).

Muscle strain exerted on lower arm and hand

During one trial, EMG electrodes loosened from the skin in one subject. Therefore, these EMG data had to be excluded from further analysis.

EMG activity while guiding the instrument through test course 1

In this test course, the subjects were asked to carry out a series of minor rotational and translation movements with the closed instrument. Figure 4 shows the EMG activity of the five muscle groups and the significant differences between the handles. Muscle activity of the FCU is highest when guiding the axial handle. The ring handle requires less muscle strain than the shank handle. The activity of the FCR is similar in all handles; however, the shank handle requires more strain than the multifunctional handle. The distribution of FDS activity is similar to that of the FCU. The axial handle requires considerably more strain than all other handles. Strain on the EDC was similar for the axial, vario, and multifunctional handles and lower for the ring and shank handles. The TH showed significantly less activity for the multifunctional handle than for the axial, ring, and shank handles.

Figure 5 shows web diagrams for each handle, which illustrate the mean values of the EMG activity expressed as a percentage of the maximal activity (RMS_{max}) in the muscle groups investigated. Each corner of the pentagon is assigned to a different muscle. The outer line corresponds to 60% of RMS_{max} of the respective muscle. Due to graphical limitation, statistical significance (see Fig. 4) is not included, but the differences in muscle strain become obvious using the web diagram. The highest muscle strain was observed for the axial handle, which shows EMG values twice as high for the FCU, FCR, and FDS as for TH and EDC. For the ring handle, the highest activity was seen in the TH and FCR. However, it is still lower than that for the axial handle. The multifunctional handle shows a low and balanced spectrum of muscle activity within 20% of the maximum in four out of five muscles.

EMG activity while guiding the instrument through test course 2

In this experiment, the instrument was rotated in the closed position through spiral-shaped wires. Figure 6 illustrates the EMG activities and statistically significant differences between the handles. Using the axial handle, the FCU was under more strain than with the vario, multifunctional, or ring handle. Vario and multifunctional handles showed high values for the finger extensors (EDC). However, EMG activity of EDC was not significantly different when manipulating the axial, multifunctional, or shank handles. No significant differences were measured for the thenar muscles during rotation with the five handles.

Similar to Fig. 5, Fig. 7 illustrates EMG activities as web diagrams for each handle. The pattern of the web

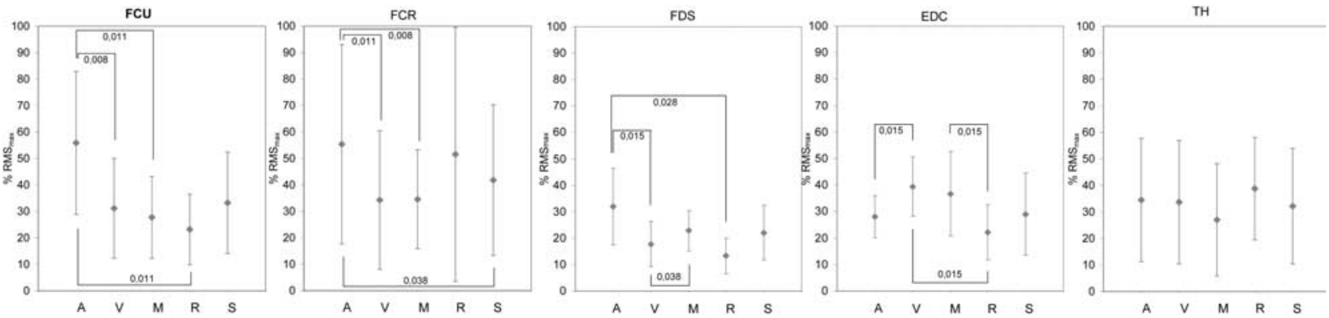

Fig. 6. Comparison of the relative EMG activities (% RMS_{max}) of the five muscle groups while guiding the instrument through test course 2, helix. The vertical bars indicate the 95% confidence interval. p values are given where differences were statistically significant. FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle.

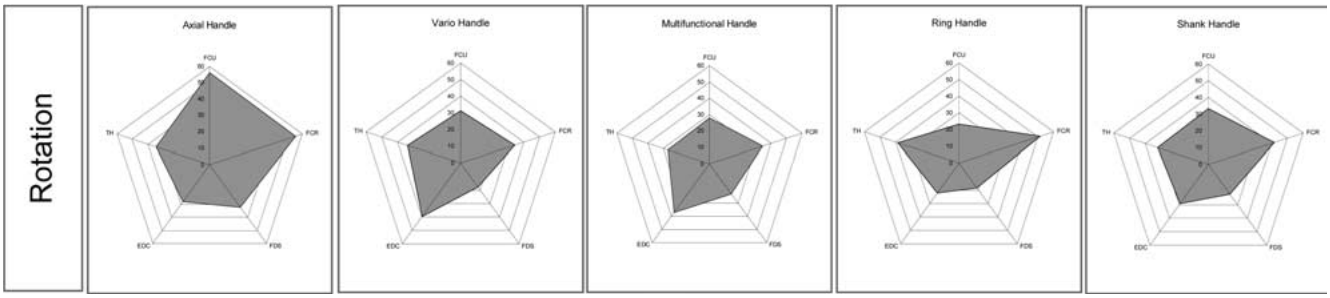

Fig. 7. Web diagrams comparing the relative EMG activities (% RMS_{max}) of the five muscle groups while rotating the instrument through test course 2, helix ($n = 9$).

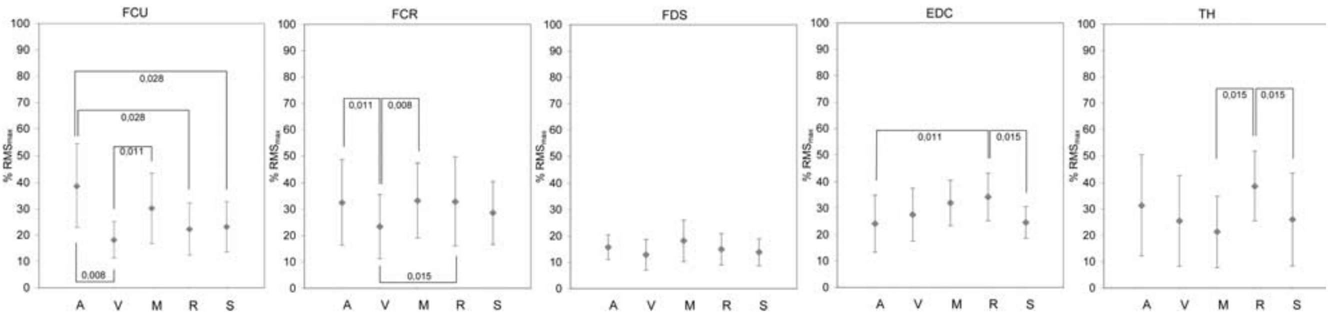

Fig. 8. Comparison of the relative EMG activities (% RMS_{max}) of the five muscle groups while opening and closing the instrument in test course 3, straddle. The vertical bars indicate the 95% confidence interval. p values are given where differences were statistically significant. FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle.

diagrams for all handles is almost identical for test courses 1 and 2, but the amplitudes increased considerably. In the axial handle, approximately 60% of the maximum activity was reached in FCR and FCU. This indicates that the function of pure rotation of the instrument requires more muscle strain.

EMG activity while guiding the instrument through test course 3

This experiment was focused on the opening and closing of the instrument while simultaneously guiding it through a curved test course. Figure 8 shows the EMG activity and the significant differences. For the axial handle, the FCU showed the highest activity for this opening/closing task. The vario handle has significantly lower values for the FCR than do the axial, ring, and multifunctional handles. For the ring handle, the EDC showed significantly higher values than the axial or shank handles, and the thenar muscles were significantly more active compared to the shank or multifunctional handles.

As in the previous web diagrams for guiding (Fig. 5) and rotation (Fig. 7), Fig. 9 shows a similar pattern of muscle activity with an intermediate amplitude compared to the previous tasks. Only for the ring handle are the finger extensors (EDC) more active.

Discussion

In this study, task performance and muscle strain were investigated under dynamic conditions for typical lapa-

Fig. 9. Web diagrams comparing the relative EMG activities (% RMS_{max}) for the five muscle groups while opening and closing the instrument in test course 3, straddle ($n = 9$).

roscopic, tasks, such as guiding, rotation, and opening/closing of the instrument. The following are the main results:

1. The task performance with respect to dropped objects and in terms of contact times to the electrical wires was similar for all five handles investigated, although the vario handle required more training than the other handles with respect to dropped objects.
2. The patterns of muscle activity, as shown in the web diagrams, varied between the handles but not between the tasks tested. This may indicate that not the laparoscopic task but, rather, the handle design determines the muscle activity pattern.
3. Despite the similarity of the muscle activity patterns between the tasks, differences were found in amplitudes: the lowest muscle activity was observed for guiding and the highest for the rotation in all handles tested.
4. The axial handle required significantly more muscle activity than the other handles.

Methodological considerations

This study investigates the handle design during three main dynamic laparoscopic tasks. Experiments have to be performed on phantoms because during real procedures on animals or humans specific tasks cannot be reproduced reliably. The focus of this study was on task performance and muscle activity using five different handles. Most of these handles are available for clinical practice and have been used in previous studies [10, 11, 14]. The vario handle is a model that was constructed and produced by our group. To avoid interference of special functions such as ratchet and cock wheel that were not available for all handles, these functions were removed, if possible; otherwise, the subjects were banned from using them. This is realistic because friction inside the instrument avoids rotation if the ratchet is fastened. Accordingly, rotational movements of the instruments were performed only by pro- and supination of the forearm.

Training in surgery is an important factor for task performance; therefore, results can be influenced depending on the experience of the subjects with a certain handle [20]. To avoid this, our subjects were recruited among non surgeons. However, other studies did not consider this problem [1, 2, 5, 6, 17]. Additionally, handles and test courses were randomized. Consequently, a training effect could not bias our results.

Task performance

Two studies found significant differences in task performance between handles [5, 20]. In contrast, we found similar task performance for all handles in a previous study. However, the test subjects considered the shank handle to be the most convenient, followed by the multifunctional handle for right-handed use and the axial handle for left-handed use [14].

During laparoscopic surgery, neighboring organs may be damaged if touched, especially if high-frequency current is used for dissection. This may result in serious complications, which are comparably rare in real procedures. In our experiments, this risk was assessed by the number and time of contact with the wires. There was no significant difference recorded for this type of error between the five different handles. However, the calculated relative contact times for all handles appeared to be very long, considering how often such intraoperative errors occur. The most likely explanation is that the test courses are very difficult and that the subjects were unable to perform any task without error. If any handle was clearly superior to the other, we should have been able to see a significant difference in error rate.

In studies involving instruments from various manufacturers, the length and difference in shape of the instrument shaft and forceps have to be considered. Accordingly, the forceps of the instruments were chosen as similar as possible in size and surface quality. An influence on the number of dropped objects is very unlikely, because most objects were dropped with the vario handle, whereas only one test object was lost with the multifunctional handle. Because both instruments had the same shaft and effector, we can conclude that the handle design, and not the effector, was responsible for the difference in this aspect of task performance.

Lost objects during a laparoscopic procedure (e.g., gallstones, tissue samples, or needles) are unacceptable because they can cause severe complications. In any case, this must not be caused by the instrument handle. Eleven test objects were dropped during a total of 100 trials on test courses 1 and 2. Seven of these test objects

(14%) were dropped in test course 1 while using the vario handle (Table 2). This may indicate that the vario handle is less suitable for guiding under slight pro- and supination while simultaneously holding a test object. There was no significant difference between the handles used on test course 2. Lack of training is the reason for the increased number of test objects dropped with the vario handle because the subjects dropped objects only during the initial attempts. We suggest that manipulation with this handle should be trained on a phantom. In fact, this should be recommended before using any new surgical instrument in the operating room.

Distribution of muscle strain

The evaluation of EMG activity is a well-known and accepted procedure in the field of ergonomic research, and it is considered useful to facilitate the improvement of the ergonomics of surgical instruments and working posture [1, 2, 5, 10, 11, 17]. While suturing, Uchal et al. [20] found no difference in muscle activity in the lower arm between a bent and an in-line ring handle. Emam et al. [5] examined three different handles for suturing. In this study, the ring handle caused more fatigue than two specially developed handle types. Our result that the axial handle required more muscle activity for the opening/closing procedure than all other handles, is in accordance with a previous study under static conditions [10].

A surprising result of our study was that the pattern of EMG activity observed is not task specific but rather seems to depend on the design of the instrument handle (Figs. 5, 7, and 9). Describing the design of a handle as a function of EMG activity may be useful to evaluate the ergonomics of handles (e.g., by detecting muscle groups that are under particular strain for a certain handle). Technical modifications should result in an improvement of the EMG pattern. However, because our study is the first to report this phenomenon, conclusions can only be drawn with caution, until it is confirmed by further studies.

A further point is that dynamic contractions with a mean EMG activity of 20% RMS_{max} are less fatiguing than continuous isometric static contractions, which can only be performed for approximately 10 min [19]. The periods of continuous muscle activity of this study were much shorter. However, a mean activity of approximately 60% RMS_{max} for the FCU and the FCR, as well as 30% RMS_{max} for the remaining muscles in the axial handle (Fig. 7), should be more strenuous than performing the same task with the multifunctional handle with muscle activities between 20 and 35% RMS_{max} for all five muscles. During real procedures, the dynamic tasks used in this study would be repeated for hours. Therefore, these differences between handles may become relevant. Indeed, pain and muscle cramps are a well-known phenomenon for MIS surgeons. Berguer et al. [3] found that MIS is mostly carried out statically. Accordingly, strain of less than 20% RMS_{max} exerted on the lower arm and the thenar muscles during long procedures may be reasonable. Higher strain could affect the precision necessary in MIS. Regarding the web diagrams in Figs. 5, 7, and 9, it is obvious that this requirement was not achieved by any handle for all muscle groups. The axial handle performed worst because it requires relatively high activity for all functions and all muscle groups. Even the ring handle, which is most often used in clinical practice, does not achieve this requirement. However, strain may be reduced by training with a handle.

Technical considerations for the different handles

Regarding the function of the individual muscles, certain elements of the handles may be improved in order to keep muscle strain within the 20% RMS_{max}. The deepest muscle layers in the lower arm cannot be differentiated by surface electrodes. For this reason, they cannot be involved in tests on instrument handles. In conjunction with agonistic and antagonistic muscles, it appears to be important that at least a representative of these groups is measured. Before the specific design elements of the individual handles are discussed, one should recall the function of the muscles tested:

FCU: The M. flexor carpi ulnaris causes ulnar bend angulation in the wrist and palmar flection, where it is more effective than the FCR.
FCR: The M. flexor carpi radialis is a pronator of the elbow joint. In the wrist, it contributes to palmar flexion and radial abduction.
FDS: The M. flexor digitorum superficial is a strong flexor of the wrist and the proximal finger joints, but it is less effective when the wrist is bent to its maximum.
EDC: The M. extensor digitorum communis stretches and spreads the fingers. It is the strongest muscle in the wrist for dorsal flection. When making a fist, it contributes by cocontraction with the flexors to stabilize the wrist.
TH: The thenar group includes the M. flexor pollicis brevis and M. abductor pollicis brevis, which cannot be measured separately by surface electrodes.

Axial handle

The subjects held the axial handle in such a way that the lever key rested on the fingers and the handle in the palm (Fig. 1). In comparison to the other handles, the axial handle requires more muscle strain than 20% of maximum muscle activity (Figs. 4–9). Muscle activity is apparently higher for rotating the closed instrument than for guiding and opening/closing the instrument. During rotating, FCU and FCR are especially active. FCU activity is explained by the large ulnar deviation of the wrist. In this position, the FCR is stretched. This element of construction cannot be altered without abandoning the principle of the axial handle.

Multifunctional and vario handles

The multifunctional handle is held in the palm, and opening and closing the forceps are performed by the

Table 3. Evaluation of EMGs and dropped test objects for all handles for the test course 1, curve

	Handle				
Curve	**A**	**V**	**M**	**R**	**S**
FCU	– – –	0	+	+ +	+ –
FCR	0	0	+	0	–
FDS	– – – –	+	+	+	+
EDC	– –	– –	0	+ +	+ +
TH	– –	0	+ + +	–	–
Dropped test objects		–			
Score	**No. of points awarded**				
+	0	1	6	5	4
–	–10	–3	0	–1	–3
Total	–10	–2	6	4	1

FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle

middle finger. The switches for HF electricity, rotation of the effector, and the ratchet are manipulated by the thumb, but these were not used in this study. FDS and EDC show high muscle activity. The reason for the EDC is the high volume of the handle that forces the hand into dorsal flexion.

The ball of the vario handle is held in the palm, while fingers 3–5 touch the branch and the index finger stabilizes the instrument from the side. In this study, the thumb was placed on the ring and was responsible for opening and closing (Fig. 1).

The patterns of EMG activity of the vario and multifunctional handle were similar. Regarding the design of these two handles, this suggests that most EMG activity is required for holding the handles and not for opening or closing them. Although both handles are held between the palm and the ulnar fingers, opening and closing are performed differently. The multifunctional handle is manipulated by the flexion of the middle finger and the vario handle by the thumb. Although the lever of the vario handle is shorter than that for all other handles, EMG activity of TH was not higher for opening and closing the instrument.

Ring handle

The highest activity was observed in the FCR because radial abduction is necessary to align the handle with the lower arm's axis, which in turn explains the relatively low activity in the FCU. The activity of the FCR should decrease if the handle could be held in a neutral wrist position. Technically, this would mean increasing the angle between the shaft and the handle.

This instrument is mainly closed by the thumb, which explains the relatively high EMG activity in the TH (Figs. 5, 7, and 9). The comparably lower activity levels for the FDS indicate that the lever arm is better for fingers 2–5 than for the thumb. It is also opened by the ring finger, which results in a relatively high EMG activity of the EDC (Fig. 9). EDC and TH activity could be decreased by increasing the levers for opening/closing.

Shank handle

In contrast to the ring handle, in which the thumb is moving, the shank handle is opened and closed by movements of fingers 2–5. The EDC is comparably low because the instrument is opened via a spring.

Is any handle superior?

To answer this question, the handles were ranked in the following way. All handles were compared using the Wilcoxon test. Comparisons were performed for the EMG of the different muscles and the number of dropped test objects. One "plus" (+) was awarded for each statistical significance to the better and a "minus" (–) to the worse handle. For example, if one handle caused significantly less strain in one muscle than did the other four handles, it was awarded four plus points. On the other hand, if a handle scored significantly lower than the others it was awarded a minus point. A minus point was also awarded where test objects were dropped. In a realistic operation, dropped objects cannot be tolerated. Therefore, no plus point was awarded if the test object was successfully guided through the course. If a handle showed no significant differences in comparison to any other handle, it was awarded a "0." Finally, all + and – points were calculated in order to achieve a sum score for the handle. Because it is not clear whether any parameter is more important for ergonomics than the others, all parameters were appraised as equal. Trial time and contact errors are not included because there were no significant differences between the handles.

Table 3 shows the results of test course 1, which simulates the precise guiding of the closed instrument through the abdomen. The axial handle (A) clearly has the worst score. The multifunctional handle (M) impresses with the absence of minus points and the most plus points compared to the ring and shank handles. The vario handle's score is mostly influenced by the number of dropped test objects because the training effect is not adopted in this evaluation.

Table 4. Evaluation of EMGs and dropped test objects for all handles for test course 2, helix

	Handle				
Helix	**A**	**V**	**M**	**R**	**S**
FCU	– – –	+	+	+	0
FCR	– – –	+	+	0	+
FDS	– –	+ +	–	+	0
EDC	+	– –	–	+ +	0
TH	0	0	0	0	0
Dropped test objects	–	–	–		
Score	**No. of points awarded**				
+	1	4	2	4	1
–	−9	−3	−3	0	0
Total	−8	1	−1	4	1

FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle

Table 5. Evaluation of EMGs for all handles on the test course 3, straddle

	Handle				
Straddle	**A**	**V**	**M**	**R**	**S**
FCU	– – –	+ +	–	+	+
FCR	–	+ + +	–	–	0
FDS	0	0	0	0	0
EDC	+	0	0	– –	+
TH	0	0	+	– –	+
Score	**No. of points awarded**				
+	1	5	1	1	3
–	−4	0	−2	−5	0
Total	−3	−5	−1	−4	3

FCU, M. flexor carpi ulnaris; FCR, M. flexor carpi radialis; FDS, M. flexor digitorum superficialis; EDC, M. extensor digitorum communis; TH, thenar muscle

Table 4 shows the results of test course 2. The negative evaluation of the axial handle (A) in this case is due to the rotating movement necessary to complete the course. This result is surprising because it is common sense among surgeons that axial handles are best for suturing in laparoscopic surgery. Suturing is a rotating movement of approximately 180°. In the helix, the instrument had to be turned more than 360°. This difference, as well as the fact that no ratchet was available in this study, could lead to the poor score. The ring handle (R) has the best score here despite its nonphysiological hand positioning. It has only positive scores. This is surprising because in the study by Uchal et al. [20] the ring handle scored worse for suturing (i.e., a rotating movement).

Table 5 shows the results of test course 3. The vario handle (V) seems to be more suitable for opening/closing movements, whereas the axial and ring handles scored worst. This result is surprising considering the short lever of the functional element in the vario handle. The shank handle (S) scored second for the opening/closing task during guidance of the instrument. This result is similar to previous measurements of EMG during static tasks, and the impressions of the volunteers during sorting and cutting tasks were similar [10, 11, 14].

Table 6. Summarized scores for all three test courses[a]

	Handle				
	A	**V**	**M**	**R**	**S**
Curved	−10	−2	6	4	1
Helix	−8	1	−1	4	1
Straddle	−3	5	−1	−4	3
Total	−21	4	4	4	5

[a] Obtained by combining the results of Tables 3, 4, 5

Table 6 shows the summarized results of Tables 3, 4, and 5. No handle seems to be superior, whereas the axial handle (A) clearly scores worst in all three tasks tested. The remaining handles show no particular differences. Regarding specific tasks, some handle designs may be superior (e.g., the multifunctional handle for guiding, the ring handle for rotation, and the vario handle for opening/closing.

For future construction of handles, it may be helpful to carefully consider muscle activities and task performance under dynamic conditions in an early stage of development to improve the ergonomics of the instrument handles.

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