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Technical Report

New Ergonomic Design Criteria for Handles of Laparoscopic Dissection Forceps

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ABSTRACT

***Background*: The shape of laparoscopic instrument handles can cause physical discomfort. This problem may be ascribed to a lack of standards for instrument design. In this study, new ergonomic requirements for the design of laparoscopic dissection forceps were created. Three representative handles (a Karl Storz [click-line] scissors handle, an Access Plus scissors handle, and an Aesculap cylindrical handle) currently available on the market were evaluated according to the new list of ergonomic criteria.**

***Materials and Methods*: The handles were subjectively (questionnaire) and objectively (video analyses) tested in order to find out whether the new requirements are valid for the evaluation and design of instrument handles.**

***Results*: The outcome of the subjective and objective tests matched the predictions by the new criteria list. New criteria were introduced (neutral wrist excursions), and existing general criteria were specified (e.g., a minimal contact area of 10 mm). Significant differences were found among the three handles. The Storz handle met 8 of the 10 requirements, the Access handle met 5, and the Aesculap handle met only 4.**

***Conclusions*: The new list of ergonomic requirements is a valid tool to determine the ergonomic value of a handle for laparoscopic dissecting tasks. It gains its strength from its specialized character. Significant differences were found among the three tested handles. Cylindrical handles were inferior to scissors handles.**

INTRODUCTION

NOWADAYS, A WIDE VARIETY OF laparoscopic instruments are available on the market. The instruments not only differ in brand and function but also in handle shape, tube length, and tip design. For example, in the group of laparoscopic dissection forceps, different tips and handles can be distinguished. In a previous study,[1] we introduced a classification of instrument functions. Four function groups were identified: for intensely manipulating tissue, for electrosurgery, for suction and irrigation, and for automatically suturing tissue. Within these function groups, clusters of different handle models were described. By means of a questionnaire, this

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There is no relation between the authors, their institutions, and any instrument manufacturers.

grouping and clustering was presented to surgeons to assess the use of laparoscopic instruments and the problems that occur during manipulation of a specific instrument. The results of this study showed that instruments classified in function group 1 cause the most discomfort. In this group, one handle type (scissors model, pistol grip, thumb manipulation) was used most frequently.

This previous study and recent other studies[2–4] showed that the shape of the instrument handle can cause discomfort. The variety of instrument handles and the experience of discomfort attributable to the handle shape may be ascribed to a lack of standards in a developing field. In the studies mentioned above, the instrument handles were evaluated according to general lists for handle design.

These general lists have a few shortcomings. First, some criteria are not operational; i.e., concrete with respect to certain functions. For example, "the handle must have a large contact area" is not an operational requirement. It is operational when it can be measured; e.g., "the contact area must be at least 50 mm^2." Second, the results obtained with these criteria do not fully meet the expectations according to subjective tests and observation of the use of dissection forceps by surgeons.[1] Therefore, we decided to develop a new list of ergonomic design criteria precisely tuned to the function group of instruments for dissection. The aim of this study was to create new validated ergonomic criteria for the design of laparoscopic dissection forceps. This will be the first list of a series of standards for function groups of minimally invasive surgery instruments.

NEW ERGONOMIC REQUIREMENTS FOR LAPAROSCOPIC DISSECTION FORCEPS

In the ergonomic literature, recommendations can be found for the design of hand tools.[5–7] The following design features related to injury or discomfort can be distinguished.

Posture of Hand and Arm

During the use of a hand tool, it is important to prevent extreme wrist and arm excursions. Nerves can be trapped, and long-term manipulation can cause carpal tunnel syndrome or tenosynovitis, especially by palmar flexion or ulnar deviation.[5] Extreme radial deviation combined with pronation and dorsiflexion can cause epicondylitis.[5] With the hand in a neutral posture, carpal tunnel pressure (CTP) remains below 3.9 kPa. A CTP above 3.9 kPa (30 mm Hg) is undesirable because it compresses the median nerve and other structures. A pressure above 3.9 kPa occurs during wrist excursions $>20°$. Therefore, a neutral zone of hand movement can be defined as movement $<15°$ of wrist extension, wrist flexion, ulnar deviation, and radial deviation.[7] The design of the handle must prevent extreme wrist positions. Ulnar deviation can be prevented by an angle between the handle and tube of 19° to 24°.[5] Adding an angle between the handle and tube also prevents abduction of the arm.

Forces in Hand and Arm

To manipulate hand tools, muscle force is needed. An important effort of the hand is grip force. Grip opening and hand posture influence grip force. When the grip opening is too big or too small, less grip force can be produced. An ideal grip opening is defined between 65 and 90 mm.[5] Extreme wrist positions reduce grip strength and should be prevented. Another important aspect of hand force is the strength of the finger flexors. These muscles are twice as strong as finger extensors[6]; therefore, manipulation force must be produced by finger flexors. This can be established by incorporating a spring.

Compressive Force on the Hand

During manipulation of a hand tool, force is applied with the hand, and compressive force is concentrated on contact areas. This compressive force causes obstruction of blood flow (ischemia) that can lead to numbness and tingling of the fingers. Therefore, the contact area should be as big as possible.[5,7]

Finger Movement

The index finger is often used to control buttons. When this finger is used excessively, a "trigger finger" (form of tenosynovitis) develops. The thumb is the only finger that is flexed, abducted, and opposed by strong, short muscles located within the palm of the hand and is therefore preferred for use on control buttons.[5]

Left Handed Users

Left-handers make up approximately 8% to 10% of the world population.[5] During laparoscopic surgery, instruments are manipulated with both hands. Therefore, hand tools must be designed for right-handed as well as left-handed use.

Anthropometry

To design a hand tool for a special target group, anthropometric data from this group must be considered. The dimensions of a hand tool are derived from the mean and extreme hand dimensions of the target group. The population of laparoscopic surgeons consists of ±90% male and ±10% female, age between 25 and 65. To make hand tool dimensions comfortable for a total target group is almost impossible. A solution is to design a hand tool in different sizes, but this is financially not a good solution. A good compromise is to design a handle that is suitable for 95% of the user group.[8]

GENERAL CRITERIA FOR THE DESIGN OF HAND TOOLS

Considering all of the above, a general list of ergonomic criteria for the design of hand tools can be generated from the literature. This list is presented in Table 1, center column.

NEW ERGONOMIC CRITERIA FOR LAPAROSCOPIC DISSECTION FORCEPS

Practical experience and recent studies[1,3,4,11] indicate that handles that seem to satisfy the ergonomic criteria can still cause discomfort. To find out what specific problems occur during surgery with existing handles, a pilot test was performed. Three surgeons used three handles during the dissection phase of a laparoscopic intervention. The general list of ergonomic criteria for hand tools was subjectively tested with a questionnaire after the intervention, and the operation was recorded on video (two cameras placed at an angle of 90°) to observe extreme wrist excursions. The outcome of this pilot study showed that subjective (questionnaire) and objective (video analyses) results did not match the prediction based on the general criteria. It showed that the surgeons do not prefer some criteria, and some general criteria are more important than others. Also, some of the criteria on the general lists are not operational (not concrete) and therefore difficult to use for the evaluation of instrument handles. The conclusions of this pilot test were:

- A spring is not preferred, because it disturbs the force feedback of tissue to the surgeon's hand.
- To manipulate a rotation knob with the index finger is not a problem, because the use is not excessive. More important is the ease of manipulating the knob. Another point is that rotation of the tip by pronation and supination of the arm is not preferred.
- An angle between the handle and tube up to 50° prevents ulnar deviation; extreme ulnar deviation

TABLE 1. GENERAL AND PROPOSED ERGONOMIC REQUIREMENTS FOR HAND TOOLS AND DISSECTION FORCEPS

	General requirements	*New ergonomic requirements*
Posture of hand and arm	Angle between handle and tube must be between 14° and 24°	Angle between handle and tube must be between 14° and 50° When handle is manipulated with precision grip, wrist excursions must be neutral in 70% of manipulation time When handle is manipulated with force grip, wrist excursions must be neutral in 70% of manipulation time
Forces in hand and arm	Grip opening must be between 65 and 90 mm Forces for opening and closing tip must be produced by flexors of the hand/fingers; this can be accomplished by use of spring for opening tip Forces for manipulating instrument must be as low as possible	Grip opening must be between 60 and 80 mm Any disturbances such as friction and spring forces must be avoided to bring about optimal force feedback of tissue to surgeon's hands If handle is manipulated in free spaces, no friction must be experienced
Compressive force on the hand	Handle must have large contact area to prevent extreme contact-area pressure	Handle must have minimum width of 10 mm to prevent extreme contact area pressure
Finger movement	Control switches must be manipulated with thumb	Instrument must be provided with knob to allow rotation tip. This control switch must be manipulated with thumb or forefinger, and when manipulated in free spaces, no friction must be experienced
Left-handers	Handle must allow left- and right-handed manipulation	Handle must allow left- and right-handed manipulation
Anthropometry	Dimensions of finger rings must be: inner length minimally 30 mm, inner width minimally 24 mm	Dimensions of finger rings must be: inner length minimally 30 mm, inner width minimally 24 mm

strongly relates to the height and the position (angle) of the operating table.
- A lot of extreme wrist excursions occur during manipulation of dissection forceps.
- A grip opening of >80 mm is too wide to perform precision tasks.
- A handle width of 5 mm or less causes discomfort (experience of pressure on the hands and fingers); a handle width of 8 mm creates less discomfort, and a handle width of 40 mm causes no discomfort.

NEW LIST OF ERGONOMIC CRITERIA FOR HANDLE DESIGN OF LAPAROSCOPIC DISSECTION FORCEPS

Considering the above, the following new requirements can be composed:

- Any disturbances such as friction and spring forces must be avoided to bring about an optimal force feedback of tissue on the surgeon's hands.
- The instrument must be provided with a knob to allow rotation of the tip. This control switch must be manipulated with the thumb or forefinger, and when it is manipulated in free space, no friction should be experienced.
- The angle between the handle and tube must be between 14° and 50°.
- The handle shape should be designed to prevent extreme wrist excursions during precision tasks (performed with a precision grip) as well as global tasks (performed with a force grip). During manipulation, extreme wrist excursions should not occupy more than 30% of the total manipulation time to prevent discomfort.
- To perform precision tasks, the grip opening cannot be too big (between 60 and 80 mm).
- The handle must have a minimum width of 10 mm to prevent excessive pressure areas.

On the basis of these findings, a new list of ergonomic criteria for the design of laparoscopic dissection forceps handles can be composed. The new list is presented in Table 1, right column.

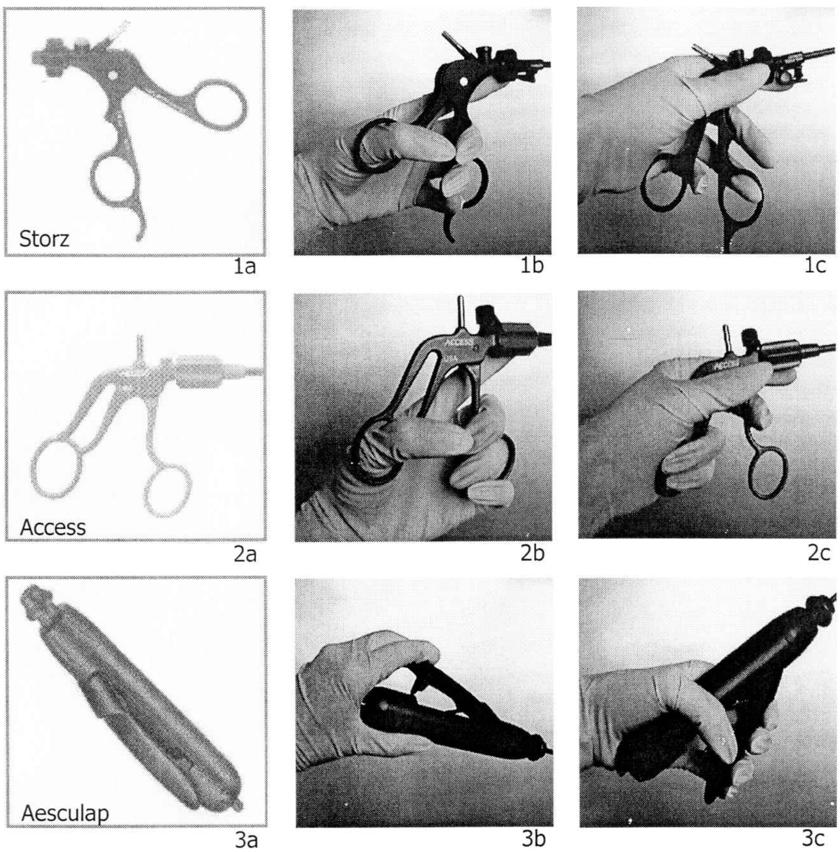

FIG. 1. The three tested handles (a) and their grips: precision grip (b), force grip (c).

MATERIALS AND METHODS

Instruments

For the test, different types of instrument handles, representative of the handles on the market, were used. In the group of dissection forceps, four handle types can be described[1]:

Scissors model, pistol grip, thumb manipulation;
Scissors model, in line;
Scissors model, pistol grip, finger manipulation;
Cylindrical model, in line.

For the scissors model, pistol grip, thumb manipulation, the Karl Storz (Tuttlingen, Germany) click-line plastic handle with connector pin without ratchet was used (Fig. 1.1a). This model can be held in two ways:

A precision grip with fingers 1 and 4 in the two rings. Finger 2 can be used for the rotation knob. To open and close the instrument tip, finger 1 is moved (Fig. 1.1b).

A force grip with finger 1 on one side and fingers 2 through 5 at the other side. Fingers 1 and 2 are used for rotating the knob, and fingers 1, 3, and 4 for opening and closing the instrument tip (Fig. 1.1c).

For the scissors model, pistol grip, finger manipulation, the Access Plus ring handle (Model 385202A; Pilling Weck, Le Faget, France) was used (Fig. 1.2a). The two ways of holding the handle are:

A precision grip with fingers 1 and 4 in the two rings. Finger 2 is used for the rotation knob. To open and close the instrument tip, finger 4 is moved (Fig. 1.2b).

A force grip with finger 1 on one side and fingers 2 through 5 on the other side. Fingers 1 and 2 are used for rotating the knob, and fingers 1, 3, and 4 for opening and closing the instrument tip (Fig. 1.2c).

For the cylindrical model, the Aesculap PM-953, without ratchet (Aesculap, Tuttlingen, Germany) was used (Fig. 1.3a). The two ways of holding the handle are:

A precision grip with fingers 1 through 5 at the back end of the handle, finger 1 on one side and fingers 2 through 5 on the other side. The instrument tip is rotated by rotating the whole instrument and is

General criteria	Storz	Access	Aesculap	**New criteria**	Storz	Access	Aesculap
1.a Angle between 14 and 24 degrees	✗	✗	✗	1.a Angle between 14 and 50 degrees	✓	✓	✗
				1.b Wrist excursions neutral precision grip	✗	✗	✓
				1.c Wrist excursions neutral force grip	✓	✓	✗
2.a The grip opening must be between 65 and 90 mm	✓	✓	✓	2.a The grip opening must be between 60 and 80 mm	✓	✓	✓
2.b Presence of a spring	✗	✗	✓	2.b No friction or other disturbances	✓	✗	✗
2.c Low opening and closing forces	✓	✗	✗	2.c No friction or other friction in free spaces	✓	✗	✗
3. Big contact area to prevent pressure area	✗	✗	✓	3. Minimum width of 10 mm	✗	✗	✓
4. Control switches manipulated with the thumb n	✗	✗	✳	4. Switches manipulated with thumb or forefinger	✓	✗	✗
5. Left- and right-handed manipulation	✓	✓	✓	5. Left- and right-handed manipulation	✓	✓	✓
6. Finger rings must be: length 30 mm, width 24 mm	✓	✓	✳	6. Finger rings must be: length 30 mm, width 24 mm	✓	✓	✳

✓ = Satisfies the requirement ✗ = Does not satisfy the requirement ✳ = Does not apply

FIG. 2. Prediction of ergonomic value of handles by general and new ergonomic requirements.

closed by flexing the fingers and opened by a spring force (Fig. 1.3b).

A force grip with the fingers around the instrument (Fig. 1.3c).

The scissors model, in line was not used, as this is an old-fashioned type that is not often used.[1]

Prediction

Predictions were made of the ergonomic value of the three handles according to both lists of requirements (the general list and the new list).

Validation Test

Seven surgeons with different levels of experience used the three instruments in a Pelvi-Trainer. The new list of ergonomic criteria was subjectively tested with a questionnaire. The answers were scored on a visual analog scale (VAS) of 100 mm. The criteria for extreme wrist excursions were objectively tested by video analyses.

The following aspects were standardized. The surgeons had to perform two tasks: one precision task with a precision grip (moving little objects from one scale to three other scales and vice versa) and one global task with a force grip (putting a cord around pillars). The Pelvi-Trainer was placed on a table, and the height of the table was adjusted to the body length of the volunteer in such a way that the body and arms were in a neutral position. The instruments were used at random. First, the precision task was performed, then the global task. After performing the test, the volunteers filled out a questionnaire.

Subjective Assessment. The following questionnaire was presented to the surgeons after the experiment:

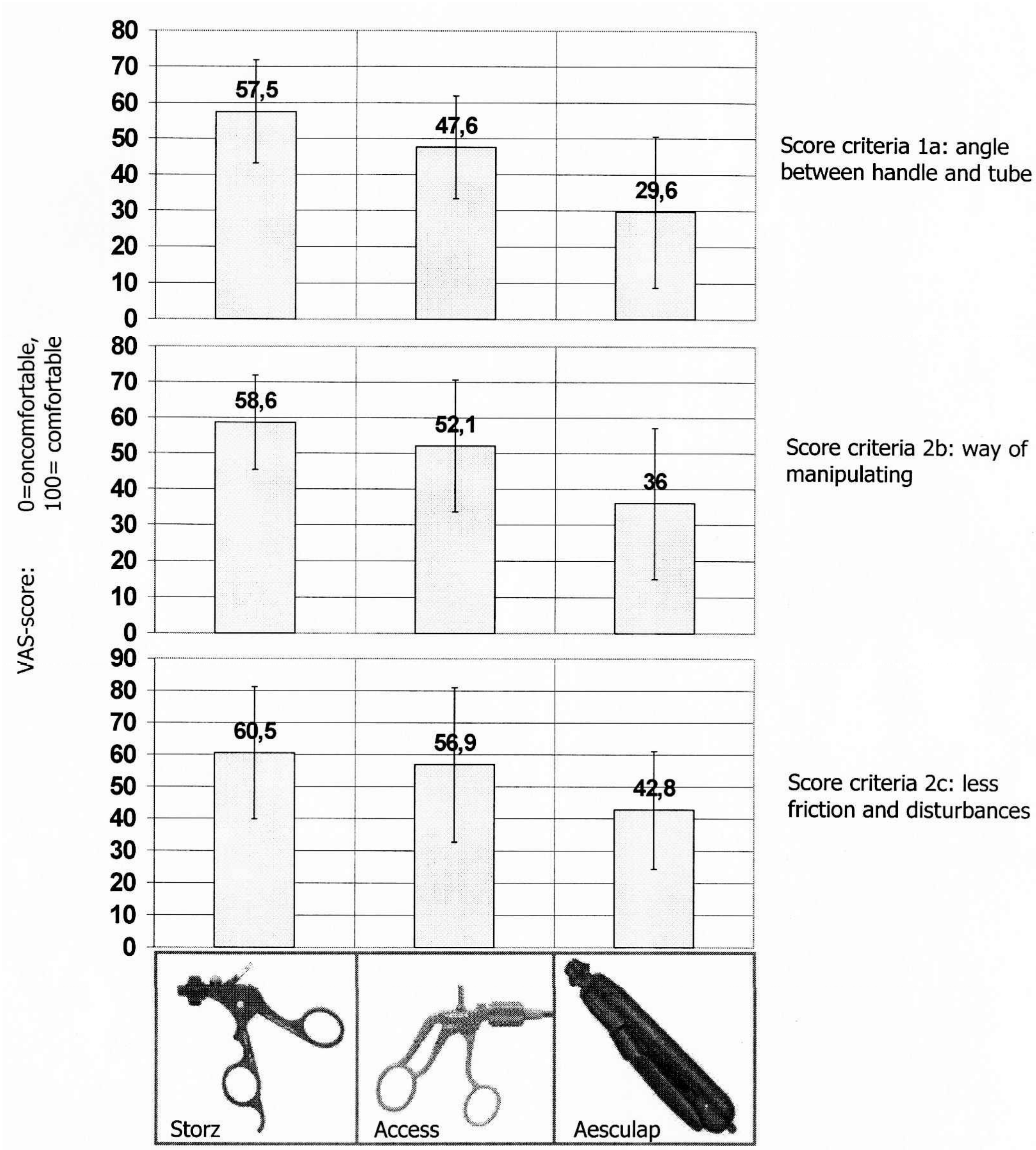

FIG. 3. Results of questionnaire concerning criteria 1a, 2b, and 2c.

1. Regarding the position of the handle with respect to the tube (angle between the handle and tube), what is your experience of comfort/discomfort during use (criterion 1a)?
2. Regarding the required opening and closing force, what is your experience of comfort/discomfort during use (criterion 2b)?
3. Regarding the way of opening and closing the instrument tip, what is your experience of comfort/discomfort during use (criterion 2c)?
4. Regarding the pressure of the handle on your hand (fingers), what is your experience of comfort/discomfort during use (criterion 3a)?
5. Regarding the rotation of the instrument tip, what is your experience of comfort/discomfort during use (criterion 4a)?
6. In what way do the dimensions of the handles agree with your hand dimensions (criterion 6a)?

For every question, the three handles had to be scored on a VAS.

Objective Assessment. Two cameras were placed at an angle of 90° to measure the positions of the hand. Neutral and extreme wrist excursions were measured. 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 regular intervals (every 2 seconds), and the angle of the hand with respect to the wrist (neutral or extreme) was rated. The amount of extreme positions was calculated as a percentage of the total amount of video frames.

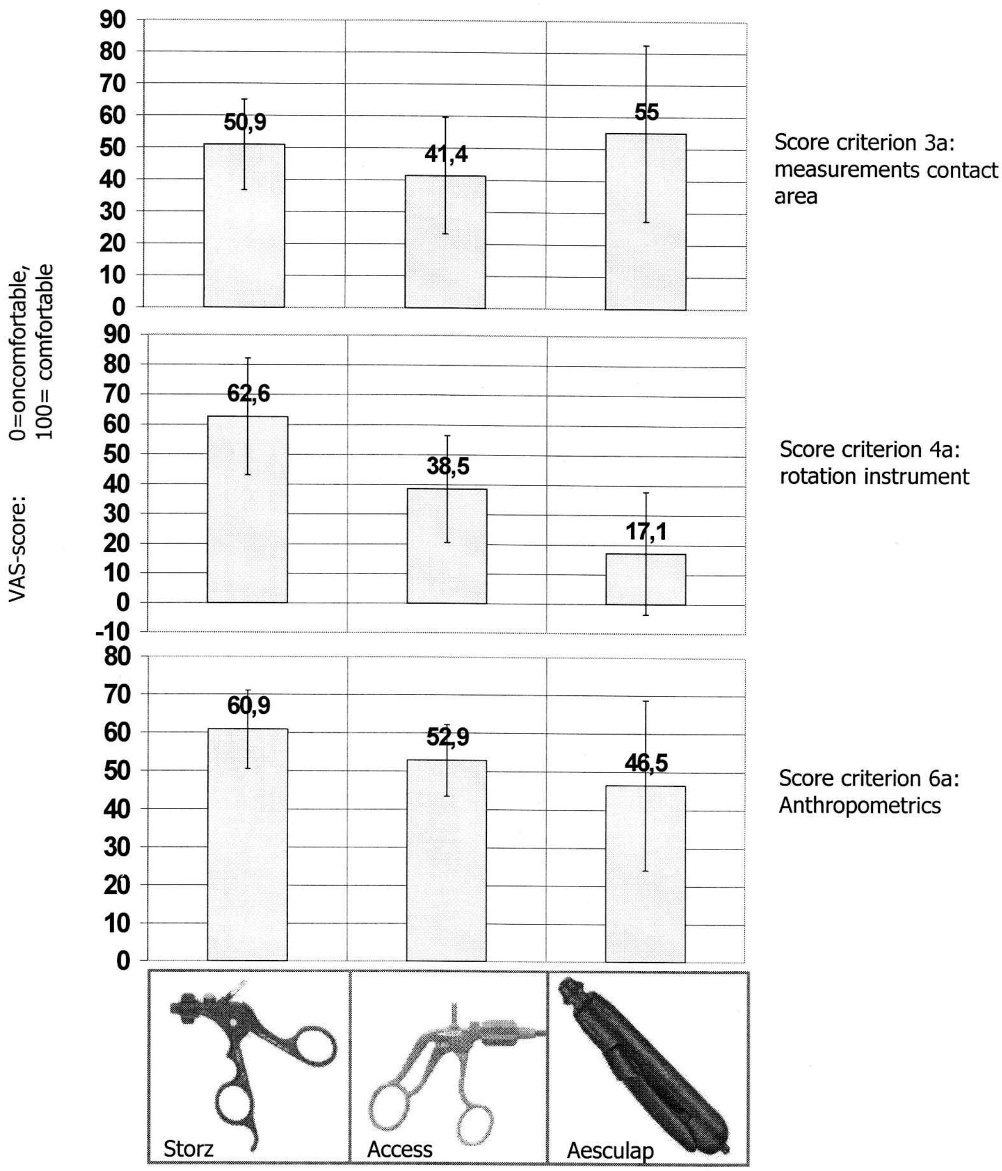

FIG. 4. Results of questionnaire concerning criteria 3a, 4a, and 6a.

Hypotheses

To measure the differences between the handles on the different aspects, the means of the results were compared. The expectation is that when one handle meets the requirement and one does not, the difference will be significant. Considering the above, the following hypotheses can be set up. For the subjective part:

H0: The VAS score on the questions of handle 1 (μ) = the VAS score on the questions of handle 2 (μ) = the VAS score on the questions of handle 3 (μ)
H1: At least one of the means is not equal.

For the objective part:

H0: The μ neutral positions of handle 1 = μ neutral positions of handle 2 = μ neutral positions of handle 3.
H1: At least one of the means is not equal.

Statistics

The results of both validation tests (subjective and objective) were analyzed with one-way ANOVA using SPSS 8.0. The level of significance was $\alpha = 0.05$.

RESULTS

Prediction by the General Criteria

In Figure 2, left column, the data from the evaluation of the three handles by means of the general list of ergonomic criteria for the design of hand tools are displayed. The Access scissors handle satisfied only three of the eight requirements, and the Storz scissors handle and the Aesculap cylindrical handle both met only four of the eight requirements. The Aesculap cylindrical handle is the most ergonomic handle according to this general list because only two requirements are not satisfied.

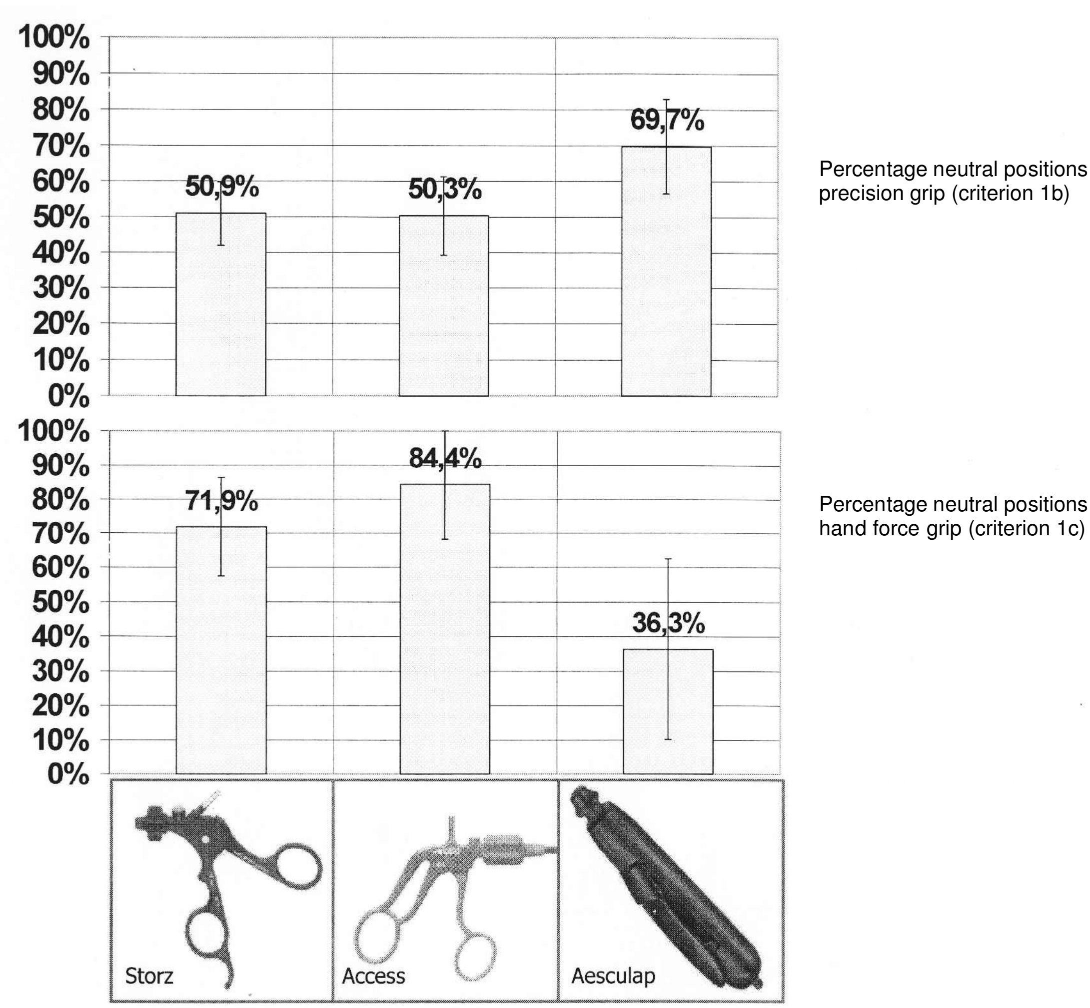

FIG. 5. Results of video analyses (criteria 1b and 1c).

Prediction by the New Requirements

In Figure 2, right column, the results of the prediction by the new ergonomic criteria are given. The Aesculap cylindrical handle satisfies only 4 of the 10 requirements. The Storz scissors handle meets almost all ergonomic criteria (8 of 10) except the criteria for big contact area and neutral wrist excursions during precision tasks. The Access scissors handle meets 5 of the 10 criteria. Aspects such as the rotation knob and contact area need to be improved.

Subjective Validation of New List of Requirements

The results of the subjective evaluation by a questionnaire are shown in Figure 3 and 4. On question 1 about the angle between the handle and tube (criterion 1a), the Storz handle scored significantly better than the Aesculap cylindrical handle ($P = 0.011$). The differences between the Storz and the Access handle are not significant.

On question 2 about the opening and closing forces (criterion 2b), the Storz handle scored significantly better than the Aesculap handle ($P = 0.043$). The differences between the Storz and the Access handle are not significant.

On question 2 about the way of opening and closing the tip (criterion 2c), the differences between the three handles are not significant.

On question 4 about the dimensions of the contact area (criterion 3a), the differences between the three handles are not significant.

On question 5 about the rotation of the instrument tip (criterion 4a), the Storz handle scored significantly better than the Aesculap handle ($P = 0.002$). The Storz handle also scored significantly better than the Access handle ($P = 0.034$).

On question 6 about anthropometry (criterion 6a), the differences between the three handles are not significant.

Objective Evaluation of New List

The results of the video observations of the position of the hand with respect to the wrist are shown in Figure 5. During precision tasks, the Aesculap cylindrical handle scored significantly better than the Storz and the Access handles (respectively $P = 0.004$ and $P = 0.0001$). During global tasks, the Storz handle and the Access handle scored significantly better than the Aesculap cylindrical handle (respectively $P = 0.02$ and $P < 0.0001$). During global manipulation with the Aesculap handle, more extreme wrist excursions were recorded.

DISCUSSION

In this early stage of the developing area of minimally invasive surgery, we noticed the need for an ergonomic criteria list for different function groups of laparoscopic instruments. Several thorough studies have been done on the ergonomics of instrument handles.[3,9] However, their conclusions are restricted to general recommendations for the design of laparoscopic instrument handles,[3] and detailed criteria regarding specific instruments such as laparoscopic dissection forceps do not exist. Also, the requirements on these general lists are not operational.[3,9] Therefore, a particular set of ergonomic requirements is needed. In this study, we could identify missing ergonomic issues such as extreme wrist excursions and the need for optimal force feedback of tissue to the surgeon's hands. A new list of requirements for the design of laparoscopic dissection forceps handles was created. The list encompasses comfortable margins of joint motion, grip openings, angles, etc. We excluded technical criteria (e.g., sterilization), aesthetic criteria (e.g., color and form aspects), and cognitive aspects (e.g., logical relations between handle manipulation and tip movement). These aspects are important for the design of instruments but are outside the scope of our study.

First, the general list was evaluated by means of a pilot study; second, a new list was composed and validated by means of a user test. To gain objective information, the volunteer group had to be various and to reflect the group of surgeons who perform laparoscopic procedures. This group of users has an age between 25 and 60 years. About 10% are female, and about 5% are left handed. The volunteers who tested the instruments had different levels of experience. One volunteer was left handed, and no female volunteer was available. The volunteers had different glove sizes, and they were skilled in the use of scissors model–thumb manipulation and the scissors model–finger manipulation. The volunteers were unacquainted with the cylindrical model. Although the number of volunteers was small and the group was not totally representative (because of the absence of a female volunteer), we do not expect any bias. The results from this group are representative for the whole population because the group of volunteers was diverse: the volunteers had different levels of experience, and they differed in hand size. The chance is small that extreme persons were selected. The results of the validation part are significant; this result would not change with more volunteers.

Another point of discussion is the technique used for the rating of extreme and neutral positions of the hand. Research by the Department of Work Environment, University of Massachusetts Lowell, showed that rating of wrist extremes (ulnar and radial deviation, palmar flexion and extension) is a reliable and valid method to determine the position of the hand (extreme–not extreme).[10]

The video stills were independently observed and examined by two persons, and both outcomes were between the 95% confidence limits.

When we compare the predictions obtained by the general and the new requirements, a few differences become clear. When we look at the results of the subjective and objective validation tests, we see that the results match the prediction according the new requirements better than by the general criteria. On criterion 1a of the questionnaire (angle between the handle and tube), the Storz handle (angle 40°) scored significantly better than the cylindrical handle (0°). Between the Access handle (50°) and the Storz and cylindrical handle, no significant differences exist. The mean VAS score of the Access handle was lower than the mean score of the Storz handle and higher than the mean score of the cylindrical handle. This result indicates that an angle between 35° and 45° is desired. Second, the use of a spring is not desirable: the differences between the scissors handles (without spring) and the cylindrical handle (with spring) were significant. Finally, the absence of a rotation knob is not desirable, and the knob must rotate without friction: the Storz handle (rotation knob with almost no friction) scored significantly better than the Aesculap cylindrical handle (no rotation knob) and the Access scissors handle (rotation knob with friction). When we look at the results of the objective video test, they also match the new requirements better: the scissors handles cause extreme wrist excursions during precision tasks, and cylindrical handles cause extreme excursions during global tasks. The differences are significant.

The outcome of the subjective and objective tests match the results of the prediction by the new design criteria and proved the validity of the list. The results do not match the general list. When the handles are evaluated by the new requirements, the outcome is in favor of the Storz handle. The Access scissors handle satisfies only 50% of the criteria, and the Aesculap cylindrical handle meets only 40% of the criteria. Although the appearance of the cylindrical handle seems ergonomically sophisticated (large contact area, easy to use), during global manipulation, the handle causes extreme wrist excursions and is difficult to use for dissecting tasks. The handle can be improved in these aspects. A positive point of the cylindrical handle compared with the two scissors handles is that during precision tasks (held with a precision grip), less extreme wrist excursions are required.

CONCLUSIONS

The new list of ergonomic criteria gains its strength from its specialized character and is a valid tool for the design and evaluation of laparoscopic dissection forceps handles. Significant differences were found between the three tested handles. For dissection tasks, cylindrical handles are inferior to the scissors handles, except on the issue of neutral wrist excursions during precision tasks.

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