Effect of Intracorporeal-Extracorporeal Instrument Length Ratio on Endoscopic Task Performance and Surgeon Movements

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Hypothesis: Better endoscopic task performance and more ergonomic movements of a surgeon’s dominant upper limb can be achieved within a certain range of intracorporeal-extracorporeal instrument length ratio.

Design: Investigating the effect of 3 intracorporeal-extracorporeal instrument length ratios (240:120 mm, level 1; 180:180 mm, level 2; and 120:240 mm, level 3) on efficiency and quality of a standardized endoscopic task (intracorporeal surgeon’s knot). Ten surgeons tied 360 knots inside a trainer in a random sequence. Task efficiency was measured by the execution time, which was recorded for each knot. Task quality was measured by the knot quality score, derived from the force-extension curves obtained by distraction of each knot in a tensiometer. Motion analysis parameters were obtained at the elbow and shoulder joints using a 3-dimensional motion analysis system (Kinemetrix Model 5.0-3D/3MBM; Medical Research Ltd, Leeds, England). The Kruskal-Wallis and Mann-Whitney tests were used for analysis.

Results: The level 3 ratio had the lowest knot quality score ($P = .07$) and longest execution time ($P < .05$). The range of movement at the elbow was significantly greater with the level 3 ratio than with the level 1 ratio ($P < .05$). The level 3 ratio also resulted in the widest range of movement at the shoulder ($P < .05$ for level 2 vs 3; $P = .06$ for level 1 vs 3). The median angular velocity was 329.5°/s, 360°/s, and 530°/s for levels 1, 2, and 3, respectively ($P = .10$).

Conclusions: Intracorporeal-extracorporeal instrument length ratio below 1.0 degrades task performance and is associated with a wider range of movement at the elbow and shoulder and a higher angular velocity at the shoulder.


Here is a great variation in the build and size of patients requiring treatment with minimal-access surgery. Because the port sites are determined by ergonomic considerations such as manipulation, elevation, and azimuth angles with respect to the operative field,¹ the current use of standard-length endoscopic instruments (360 mm) for all patients and different procedures results in varying intracorporeal-extracorporeal length ratios. These variations in the pivot points (at the anterior abdominal wall) along the length of the instrument are likely to influence execution, such as the force needed to perform certain tasks and the pattern of hand-arm movement outside the body cavity to effect specific manipulations within the operative field. To our knowledge, there have been no published studies on the optimum intracorporeal-extracorporeal instrument length ratio needed for minimal-access surgery. This has been addressed in the present study, which was designed to investigate the effect of 3 intracorporeal-extracorporeal instrument ratios on endoscopic task performance and patterns of upper-limb motion of the surgeon.

RESULTS

One hundred twenty knots were tied at each level. Table 1 presents the median and interquartile range of the execution time and KQS for the 3 levels investigated. Level 3 had the lowest KQS and the longest execution time.

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The median (interquartile range) of motion analysis parameters at both the elbow and the shoulder are given in Table 2.

At the elbow, there was no significant difference between the 3 levels for...
MATERIALS AND METHODS

TASK

The standardized task consisted of tying an intracorporeal surgeon’s knot (a double half-knot followed by 2 single knots) from a 200-mm length of 2-0 silk inserted through a 25 × 75 × 155-mm block of light yellow foam. A longitudinal groove in the middle of the back of the foam housed a rubber tube. The foam was mounted with Velcro on the oblique surface of a right-angled block of wood. Two silk threads were passed around the rubber tube, one at each end of the block, at a distance of 30 mm from the middle of the foam. At each site, the thread was passed around the rubber tube from behind the foam with a 10-mm distance between the entry and exit points on the foam. Equal lengths of thread were left protruding for the surgeon to tie the knot. The assembled task rig was stabilized in place inside a box, the measurements of which were 450 × 350 × 250 mm. The base, sides, and back of the box were made of wood, while the front and the top were constructed of cardboard attached to the wood with Velcro. Strips of neoprene were sutured to the cardboard (10-mm thick) for insertion of ports. This allowed maneuverability of the instruments while retaining the port positions.

EQUIPMENT

Video endoscopic equipment used included a forward-viewing endoscope, 10 mm in diameter, coupled to a single-chip camera (Endovision 9050-PB; Karl Storz, Tuttingen, Germany) and a high-resolution monitor (Model PVM-1443MD; Sony, Tokyo, Japan).

The Kinemetrix motion analysis system (Figure 1, left) has an infrared pulse generator and controller unit, 3 charged-coupled device cameras with coaxial infrared arrays and daylight-cut filters, an interface card for a PC, and a monochrome video monitor.

EXPERIMENT

Endoscopic needle drivers of standard length (360 mm) with finger-loop handles (26173 SK; Karl Storz) were used. Three levels of intracorporeal-extracorporeal instrument ratios were investigated: 240:120 mm (level 1), 180:180 mm (level 2), and 120:240 mm (level 3) (Figure 2). The task rig was raised on 2 wooden blocks of appropriate height to achieve the level 2 and level 3 conditions. Ten surgeons with variable laparoscopic experience participated in the study. Each surgeon performed 36 intracorporeal knots in 3 sessions, each consisting of 12 knots in random sequence. After tying the knot, the thread loop around the tube was divided at the opposite end to the knot. All the knots performed by each operator were numbered and coded for the operator, level, and session. The execution time was measured from the moment the surgeon grasped the handle of the needle driver until the instrument was released on completion of the knot.

The monitor was placed on a special stand so that its center was at the surgeon’s eye level and at a distance of 1 m. The endoscopic trainer was placed on a table of adjustable height so that the surgeon held the needle drivers with the shoulder adducted and the elbow at a right angle. The endoscope was introduced in the simulator so that the optical axis was perpendicular to the target surface at the knot.

There was an improvement in the execution time in session 3 compared with the first session with levels 1 and 2 (P < .05 and P = .05, respectively), whereas no improvement was observed with level 3 (Table 3).

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maximum angle, minimum angle, and angular velocity. The range of movement was, however, significantly greater with level 3 than with level 1 (P < .05), while no significant difference was found between levels 1 and 2 or between levels 2 and 3.

At the shoulder, level 3 was associated with the widest range of movement (level 2 vs 3, P < .05; level 1 vs 3, P = .06; and level 1 vs 2, P = .80). The median angular velocity with level 3 was higher than with levels 1 and 2.

COMMENT

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Figure 1. Left, The Kinemetrix motion analysis system. Right, Monitor display of the reflections from the markers tracked by the system.
The needle drivers were inserted to make a manipulation angle of 60°, elevation angle of 60°, and azimuth angles of 30°. Illumination of the operative field was kept the same throughout the experiments.

**MOTION ANALYSIS**

The motion of the dominant upper limb of the surgeon was recorded using 3 infrared cameras to track and analyze the movement of 5 reflective markers (10-mm spheres) fixed on the skin with double-sided adhesive tape. The markers were placed on the middle of the clavicle, tip of the coracoid process, lateral epicondyle, styloid process of the radius, and the head of the first metacarpal bone. The video image was processed by a single board that was fitted into one of the expansion slots of a PC. The lightweight reflective markers were completely unobtrusive and did not encumber the surgeons, while the software ensured accuracy by calculating the center of reflection. The coaxial pulsed infrared lighting ensured that fast movements were recorded for every other knot in sessions 1 and 3 and adjusted to the execution time for each knot. The maximum and minimum angles, range of movement, and angular velocity at the shoulder and elbow joints were calculated from the captured data. The shoulder angle was defined as the inner angle between markers on the midclavicle, coracoid process, and lateral epicondyle, and the elbow angle as the inner angle between markers on the coracoid process, lateral epicondyle, and styloid process of the radius.

**KNOT QUALITY SCORE**

Testing of knot quality was performed using an Instron tensiometer (Model 1026; Instron Ltd, Wycombe, England). The 2 ends of the divided loop of the knot were fixed in the jaws and distracted by the tensiometer. Signals from the load cell were fed to a signal-conditioning unit and a filter to remove the high-frequency noise. The modified signal was recorded by an analog-to-digital conversion card with a sampling frequency of 25 Hz (Advantech PCL-812PG; Roldec System, Wolverhampton, England) inserted in the computer recording system. A software program (DASYlab2, version 2.00.17; DASYTEC GmbH, Moenchengladbach, Germany) controlled the conversion card and displayed the load cell waveform. A data analysis program (Matlab; Math Work Inc, Natick, Mass) was used to smooth the data by digital filtering, remove zero offsets, apply the load cell calibration factor, synchronize each record using a digital trigger, derive extension correlates to the force data, and calculate knot quality parameters. Analysis of force extension curves provided the knot quality score (KQS). The KQS is nondimensional and represents a percentage fraction of the score for the ideal perfect knot.

**STATISTICAL ANALYSIS**

The data of KQS, execution time, and parameters of motion analysis were not normally distributed. Nonparametric tests such as the Kruskal-Wallis and Mann-Whitney tests were used as appropriate. Significance level was set at $P = .05$.
patients. Thus, ideally, endoscopic surgical instruments should be available in 3 different lengths, and with extrapolation from our data, these should be standard (360 mm) for most adult patients, short (300 mm) for smaller adults, and mini (200-240 mm) for pediatric patients. Problems caused by a small intracorporeal-extra-
corporeal instrument ratio are especially relevant to pediatric surgery, where the operative field and intracorporeal work space are reduced compared with adult surgery.

This work was supported by a grant from the Egyptian Government (Dr Emam).

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REFERENCES