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# Task Performance in Endoscopic Surgery Is Influenced by Location of the Image Display

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**Objective**

To investigate the influence of image display location on endoscopic task performance in endoscopic surgery.

**Summary Background Data**

The image display system is the only visual interface between the surgeon or interventionist and the operative field. Several factors influence the correct perceptual processing and endoscopic manipulation from images. One of these is location of the image display with respect to the surgeon and to the operative site. The present study was conducted to investigate whether endoscopic task performance improves under two conditions: when the surgeon-to-monitor visual axis is aligned with the forearm-instrument motor axis and when the image display is close to the operator's manipulation workspace.

**Methods**

An endoscopic task (tying an intracorporeal surgeon's knot) was performed under standardized conditions except for varying monitor locations. These altered the direction of view—in front of, to the left, and to the right of the operator's head and hands. In each of these view directions, the monitor was placed at the surgeon's eye level and lower down, at the level of the operator's hands. The outcome measures were the execution time, knot quality score and performance quality score.

**Results**

Task performance was better with frontal view direction: execution time was shorter ($p < 0.0001$) and the performance score was higher ($p < 0.005$) than with side viewing, with no significant difference between right and left viewing directions. With frontal view direction, hand-level "gaze-down" viewing resulted in a shorter execution time ($p < 0.01$) and a higher performance score ($p < 0.01$) than eye-level viewing.

**Conclusions**

Task performance improves when the image display is placed in front of the operator, at a level below the head and close to the hands.

Minimal access surgery differs from conventional surgery in that it uses an image display system as the visual interface between the surgeon and the operative field. Current operating rooms were designed for conventional open practice, and their ergonomic layout is not ideal for endoscopic surgery and the various high-technology devices it requires. The resulting crowding with freestanding equipment often precludes optimal placement of the viewing monitor in front of the surgeon, who usually operates from one side of the patient. In consequence, the visual axis between the surgeon's eyes and the monitor is no longer aligned with the hands and instruments. Furthermore, the monitor is often far removed from the surgeon, and thus the spatial location of the display system is remote from the manipulation workspace (hands) of the operator.

The present study was based on the hypothesis that endoscopic task performance improves under two conditions: when the surgeon-to-monitor visual axis (midpoint between the surgeon's eyes to the center of the screen) is aligned in the same vertical plane with the forearm-instrument motor axis, and when the image display system is close to the operator's manipulation workspace.

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## MATERIALS AND METHODS

The endoscopic task consisted of tying an intracorporeal surgeon's knot under standardized endoscopic conditions.

The direction of the monitor relative to the surgeon's head and the vertical level of the monitor relative to the surgeon's manipulation workspace (hands) were investigated. The study was designed to control for three factors: different levels of task difficulty, by using three positions of the instruments; different aptitudes of task performance, by recruiting 10 endoscopic surgeons for the study; and the effect of practice, by performing the experiments in three practice runs. Control measures included using the same environment and equipment throughout the experiments. Each knot was tested by distraction tensiometry. The outcome measures were the execution time and parameters of knot analysis.

## Task

The standardized task consisted of tying an intracorporeal surgeon's knot using a 200-mm length of 2-0 silk inserted through a block of yellow foam. A longitudinal groove in the middle of the back of the foam housed a rubber tube. The thread was passed through the foam around the tube with a distance of 10 mm between the entry and exit points. The assembled task rig was placed inside a trainer in which the front and the top were made of cardboard. Strips of neoprene were sutured to the cardboard to allow maneuverability of the instruments while retaining the port positions.

## Videoendoscopic Equipment

Hopkins I 0°, 30°, and 45° endoscopes were connected to a cold-light fountain 450V light source using 495NL fiberoptic light cables (Karl Storz, Tuttlingen, Germany). The Endovision 9050-PB single-chip camera (Karl Storz) and a Sony PVM-1443MD high-resolution monitor (Sony, Tokyo, Japan) were used for the experiments. The camera was adjusted on white balance. The intracorporeal knots were performed using a pair of 26173SK Cuschieri needle drivers introduced though 5.5-mm ports (Karl Storz).

## Experimental Procedures

### Monitor Positions

The monitor was placed at three viewing directions relative to the operator's head stance and motor (forearm) axis: straight in front, to the right, and to the left. At each direction, two vertical height levels of the monitor were investigated: at the surgeon's eye level and at the level of the surgeon's hands. The monitor was tilted to face the surgeon so that the visual axis was perpendicular to the monitor plane and to the line joining the surgeon's eyes (Fig. 1). A special monitor stand was used to adjust monitor location. In all positions, the distance between the center of the monitor and the surgeon's eyes was kept constant at 1 meter.

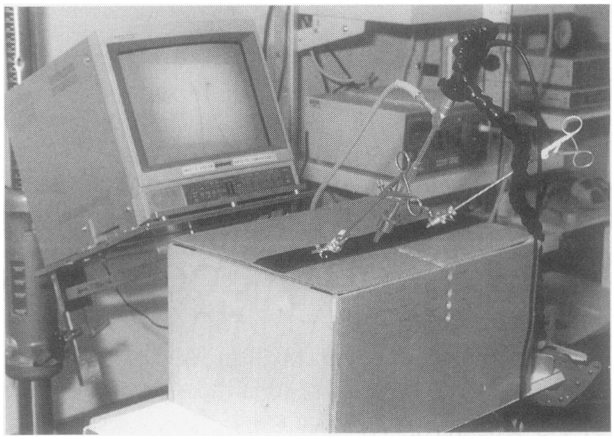

**Figure 1.** Experimental setup with the monitor in front of the surgeon at the manipulation workspace to allow gaze-down viewing by the operator.

### Instrument Positions

Three positions of different levels of difficulty were selected from previous experiments: low degree of difficulty (30° endoscope and 60° manipulation angle); medium degree (45° endoscope and 90° manipulation angle); and high degree (0° endoscope and 30° manipulation angle).[1] Endoscopes were introduced so that the optical axis was perpendicular to the target surface at the knot location, with a 75-mm distance between the objective of the endoscope and the knot. The endoscopic trainer was placed on a table of adjustable height so that the surgeon held the needle drivers with his or her elbow at a right angle and the forearm in the horizontal plane.

### Subjects and Practice

Ten endoscopic surgeons with corrected eyesight participated in the experiments. Each surgeon completed the study in three equal sessions. Each session consisted of two knots in each of the 18 locations of the instruments (three positions) and monitor (six positions). The order of positions in each session was in a random sequence. The time taken to execute each knot was measured from the moment the operator grasped the handles of the needle drivers until the instruments were released on completion of the knot. After tying the knot, the thread loop around the tube was divided at the opposite pole to the knot.

## Knot-Testing Apparatus

The two ends of the divided loop of the knot were inserted between the jaws of the clamps and distracted by Instron tensiometer (Model 1026, Instron, High Wycombe, United Kingdom). Signals from the load cell were fed to a conditioning unit to modify and filter the signal. The modified signal was recorded by an analog-to-digital conversion card (Advantech PCL-812PG, Roldec System, Wolverhampton, UK) inserted in the computer recording system. A

**Table 1. EFFECT OF MONITOR LOCATION ON THE TASK EFFICIENCY AND TASK QUALITY (MEDIAN AND INTERQUARTILE RANGE)**

| Level/Direction | HL/Rt | EL/Rt | HL/F | EL/F | HL/Lt | EL/Lt | p* |
|---|---|---|---|---|---|---|---|
| Time (sec) | 80 (30.7) | 75 (33.0) | 65 (26.7) | 72 (27.5) | 78 (29.7) | 75.5 (33.0) | <0.0001 |
| KQS (%) | 30.1 (18.2) | 28.9 (19.3) | 31.4 (16.5) | 29.6 (18.5) | 31.6 (17.3) | 29.5 (16.9) | 0.08 |
| PQS | 29.4 (24.9) | 28.9 (24.5) | 37.3 (25.9) | 31.9 (22.6) | 31.3 (25.8) | 28.8 (21.5) | <0.001 |

HL = hand level; EL = eye level; Rt = side view direction to the right; Lt = side view direction to the left; F = frontal view direction in line with surgeon's hands; KQS = knot quality score; PQS = performance quality score.
* Kruskal-Wallis one-way ANOVA.

program (Snapshot, HEM Data, Southfield, MI) controlled the conversion card and displayed the load cell waveform. A data analysis program (written in Matlab, The Math Work, Natick, MA) was used to analyze force-extension curves.

## Endpoints of Knot Analysis

The knot quality score (KQS) was derived by dividing the product of the knot breaking or slipping force and the integrated force for the knot by the product of the thread breaking force and the integrated force for the thread, and multiplying by 100%.[2] By expressing the breaking forces, slipping forces, and integrated forces as ratios of the values for untied ligatures, the KQS compensates for the breaking force and strength of the thread and has a degree of independence of thread length and jaw creep. The breaking or slipping force reflects the strength of the knot. The maximum force necessary to break the knot was defined as the breaking force; the slipping force required to undo the knot without breakage of the thread was defined as the average force of the plateau of the curve. The integrated force of the initial slope of the curves is an index of knot tightening.

The performance quality score (PQS) relates the quality of the knot to the execution time and was derived by dividing the KQS by the execution time score. The execution time score relates the execution time for each knot to a norm-referenced execution time (in this study, the mean execution time for the entire population).

## Statistical Analysis

The data of the execution time, force, work done, KQS, and PQS were not normally distributed. Nonparametric tests such as Kruskal-Wallis one-way analysis of variance and Mann-Whitney test were used as appropriate. Significance was set at the 5% level.

## RESULTS

## Monitor Position

Table 1 shows the median and interquartile range of the execution time and KQS for the different monitor positions. The values in this table were obtained by grouping the three levels of difficulty for each monitor position. The best performance was obtained with the monitor at hand level and in front. This position produced the shortest execution time with all degrees of difficulty ($p < 0.01$).

### *Direction of View*

A shorter execution time ($p < 0.0001$) and a higher PQS ($p < 0.005$) were observed when the frontal view direction was used compared to the left or right viewing direction. This significant difference in the execution time was obtained for all degrees of difficulty ($p < 0.01$). There was no significant difference in the execution time or parameters of knot analysis between the right and left viewing directions.

### *Level of Monitor*

During frontal viewing, performance was better with hand-level image display location; execution time was shorter ($p < 0.01$) and the PQS was higher ($p < 0.01$) when compared to the eye-level location. This enhanced performance in the hand-level image display location was also observed during left- and right-side viewing in terms of higher KQS ($p = 0.05$, $p < 0.05$), although the execution times did not differ from those obtained in the eye-level location.

## Instrument Position, Surgeon, and Practice

The median execution times were 64, 78, and 82.5 seconds and PQS was 37.6, 29.3, and 28.0 for low, medium, and high degrees of difficulty, respectively ($p < 0.0001$).

There was a significant difference between surgeons in the execution time, KQS, and PQS ($p < 0.0001$). The shortest median execution time was 60.5 seconds, the longest 102 seconds. The median KQS ranged from 25.7% to 46.4%, and the PQS of some surgeons was 50% of others.

With practice, surgeons performed knots more quickly (median execution time 81, 75, and 69.5 seconds, respectively; $p < 0.0001$) (Fig. 2A) but with a lower KQS (median

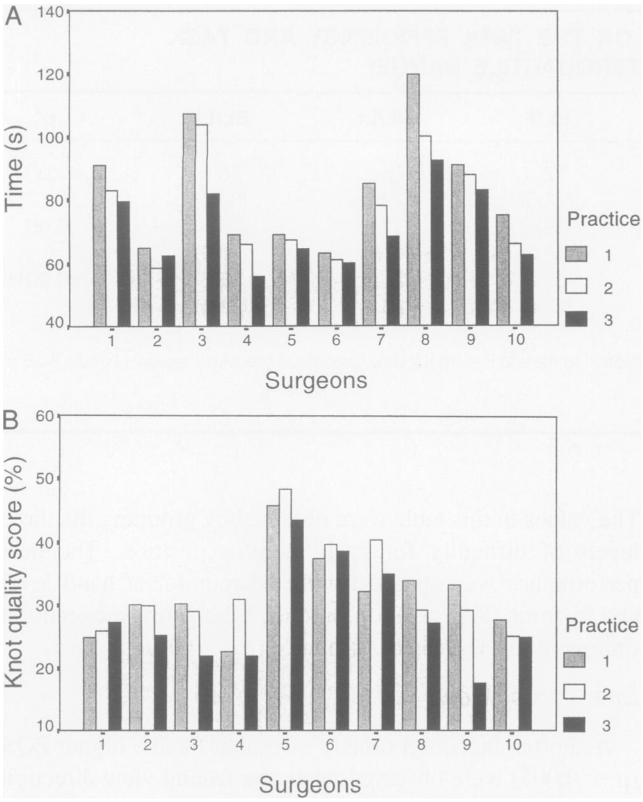


**Figure 2.** (A) Median execution time for each surgeon with each practice run. All surgeons except 2, 5, and 6 significantly improved their execution time with practice. (B) Median KQS for each surgeon with each practice run. Surgeons 2, 3, 4, and 9 had a significantly lower KQS with practice.

31.4, 31.2, and 27.5%, respectively; $p < 0.001$) (Fig. 2B). Overall, there was no significant difference in PQS with practice ($p = 0.29$).

## DISCUSSION

The results of the study have confirmed that the best task performance is obtained with the monitor located in front of the operator at the level of the manipulation workspace (hands), permitting gaze-down viewing and alignment of the visual and motor axis. Gaze-down viewing by an endoscopic operator allows both sensory signals and motor control to have a close spatial location and thus bring the visual signals in correspondence with instrument manipulations, similar to the situation encountered during conventional open surgery. These conclusions are independent of the grade of task difficulty or practice of the operator. The results are in agreement with the research on video workstations that demonstrated that graphic performance improves with gaze-down viewing compared to gaze-forward and gaze-up viewing by the workers.[3]

There are important implications of these results to minimal access surgery and to other image-guided interventional therapeutic procedures (*e.g.*, interventional radiology, flexible endoscopy). In current endoscopic surgical practice, the operator usually operates from one side of the patient or between the patient's legs, away from the image display system, which is often not directly in front of the surgeon because of the need to accommodate staff and anesthetic and other equipment.

Alignment of the operator's head stance with the monitor and manipulation workspace appears to be essential for efficient cerebral processing of the image displayed on the monitor. Performance is maximized by having the image display low and close to the operator's hands, enabling gaze-down viewing. These requirements necessitate altering the design of the operating room and operating table to improve the ergonomic layout. In addition, technology that projects the image onto the manipulation workspace is needed. This could be achieved by head-up display systems, which project the image on collimating glass, although these systems are known to cause eye accommodation problems.[4]

The best technical solution would project the image back on top of the patient, above but close to the real operative field. The surgeon would then be looking down at the organs and instruments in the operative field much as in open surgery, as if there were no intervening abdominal wall (''virtual laparotomy''). Such a system, known as ''suspended imaging,'' is still in its prototype stage and is being developed by the University of Dundee and Central Research Laboratory. The suspended image display technology uses precision retroreflector and advanced beam-splitting technology for projecting an image in space.[5,6] In the absence of these developments in image display technology, the use of flat television screens may allow better placement of the monitor in close proximity to the operative field.

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