Optimizing Surgical Approach for Natural Orifice Translumenal Endoscopic Procedures
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What is This?
Introduction

Natural orifice translumenal endoscopic surgery (NOTES) is a promising surgical technology. It uses a flexible endoscopic platform and combines aspects of laparoscopic surgery and flexible endoscopy. With the recent advances in image display and remote manipulation technologies, surgery on the abdominal cavity is feasible via various natural orifices such as the mouth, anus, urethra, and vagina. In NOTES, a transvisceral incision is made in a hollow organ to gain access to organs in the peritoneal cavity. By eliminating the need for abdominal incisions, NOTES has the potential to reduce the incidence of surgical-site hernias, abdominal adhesions, and postoperative incisional pain; it also eliminates any visible scarring.

Although the minimally invasive benefits of NOTES are desirable for patients, NOTES poses new and greater technical challenges for surgeons when compared with open or even laparoscopic surgery. From the human factors standpoint, the most serious challenge of NOTES is the perception-motion integration problem—that is, how to maintain dexterity in manipulating surgical instruments under an unstable and remotely displayed surgical site.
the surgeon and the assistant who are controlling the instruments.

Studies conducted outside of the health care setting have shown that malalignment between the displayed image and the actual working site introduces a difficult scenario for mental calibration in remote manipulation. These studies showed that performance of a task under irregular image malalignment was more challenging than performing the same task when the image was misaligned by 180°. Other studies have shown that in laparoscopic surgery, task performance has been jeopardized as a result of image malalignment. In this study, we intend to quantify the impact of image malalignment caused by endoscope retroflexion in a simulated NOTES task.

We hypothesize that when the surgical site is viewed in a retroflexed fashion, surgeons who perform the task must readjust their movements appropriately to accommodate for the retroflexed image, in turn prolonging the overall task time when compared with performing the same task under the forward-view condition. To test our hypothesis, a simulated dry-lab NOTES task was performed by a group of experienced NOTES surgeons and novices under 2 viewing conditions. We expect that our results will help provide additional consideration for surgeons when they are setting the surgical approach for performing a NOTES operation.

Methods

Apparatus and Task

Data collection was conducted in the surgical skills training laboratory. Our simulation model for NOTES used a hollow plastic sphere (5 inches in diameter) placed behind a surgical drape suspended by a metal frame (14.5 inches in height, 14 inches in width, and 0.5 inches in depth). This barrier obscured the surgical task from the direct view of the operator and ensured that the task was completed using only the view displayed on the monitor. A small circular opening (1.5 inches in diameter) was placed in the surgical drape to allow for passage of the scope.

A single-channel therapeutic endoscope (1T-160, Olympus, Tokyo, Japan) was passed through the opening in the drape and aimed toward the entrance of the plastic sphere. Four colored dots were placed around a central point on the inner surface of the sphere. Each dot was labeled with a number ranging from 1 to 5, including the central point. Each participant was required to visually locate these 4 dots and touch the dots in a predefined order using an endoscopic grasper inserted through the working channel on the endoscope (Figure 1).

Procedure

This task was performed under 2 experimental conditions: (1) forward-view condition, where the entrance of the sphere faces the operator (Figure 2A); (2) retroflexed-view condition, where the entrance of the sphere is opposite to the operator (Figure 2B). Under the second condition, the participant was required to retroflex the tip of the endoscope over 150° to capture the image of the dots.

Each participant was allowed to complete 1 trial prior to testing in order to verify a correct understanding of the task. No additional task training was given. All participants executed the task 5 times under each experimental condition. For each trial, the task time was calculated from the moment when the grasper was deployed from the tip of the endoscope and touched the central point to the moment when the fifth dot was correctly touched.

Participants

A total of 10 participants were recruited for this study, including 5 laparoscopic surgeons with extensive experience in flexible endoscopic procedures and 5 participants...
naïve to laparoscopic or endoscopic procedures. A pretest questionnaire was given to all participants to assess endoscopic and laparoscopic experience as well as to record demographic data. Experts included senior surgeons specializing in laparoscopic surgery and minimally invasive surgery fellows. All the experienced surgeons routinely perform more than 100 laparoscopic and endoscopic procedures per year.

**Evaluation and Statistical Analysis**

All tasks were video recorded. Task performance score was evaluated by task completion time (in seconds). A $2 \times 2$ ANOVA (2 groups of surgeons for 2 viewing conditions) was performed using SPSS statistical software (SPSS 18.0, SPSS Inc, Chicago, IL) to compare mean times for each group. $P < .05$ was considered significant. Results are reported as mean, standard deviation, and range unless otherwise stated.

**Results**

In all, 10 participants were recruited for this study (5 experienced laparoscopic and endoscopic surgeons and 5 novices). All participants completed the required trials under both experimental conditions, and all data were included for further analysis. Demographics for both groups are included in Table 1.

Tasks performed under the forward-view condition were significantly faster (31 ± 15 s; range, 14-55 s) than those performed under the retroflexed-view condition (50 ± 28 s; range, 14-109 s; $P = .005$). On average, the experts finished tasks in less time (27 ± 10 s; range, 14-39 s) than the novices (53 ± 27 s; range, 35-109 s; $P = .042$). Secondary analysis of the interaction between Viewing Condition and Experience Group revealed that experts and novices responded differently to each image-viewing condition. The experts performed slightly worse in the retroflexed view (34 ± 11 s; range, 14-39 s) than the forward view (21 ± 3 s; range, 14-28 s) condition. In contrast, the novices were much more vulnerable to the malalignment between the displayed image and the actual surgical site; their performance deteriorated significantly in the retroflexed condition (66 ± 32 s; range, 42-109 s) compared with the forward condition (40 ± 16 s; range, 37-55 s; Figure 3).

**Discussion**

The results of this analysis support our research hypothesis: the retroflexed-viewing condition does impede performance while performing NOTES tasks. The reason, we believe, can be attributed to increased difficulty in eye–hand coordination related to the NOTES procedure. Unlike laparoscopy, which requires one level of mental calibration by changing the viewing perspective from the eyes to the laparoscope, NOTES requires additional mental work because the viewing perspective of the endoscope is constantly changing over the course of the procedure. The endoscope must constantly be maneuvered to maintain the horizon and keep track of spatial orientation. The changing perspective of the endoscope also internally changes the configuration of the surgical instruments. When performing NOTES procedures while the endoscope is retroflexed, a higher level of mental calibration must be included in the mental adjustment of a surgeon, which can contribute to loss of orientation and dexterity.

To alleviate the mental workload of the operating surgeon during NOTES procedures, we suggest that the surgical approach be chosen carefully to avoid using the retroflexed view whenever possible. For example, selecting the transvaginal or transcolonic approach when performing a NOTES cholecystectomy or a transgastric approach for performing appendectomy may be favorable.

In the current study, it was found that experienced surgeons were able to perform tasks under the retroflexed condition with minimal delay when compared with the novice group. This could be attributed to the fact that the group of expert surgeons who were tested are located at a high-volume urban medical center and perform a large volume of endoscopic as well as laparoscopic procedures. Extensive endoscopic experience allows experts to develop sophisticated cognitive strategies to deal with malalignment between perception and movement as presented by NOTES procedures. Evidence presented in this study indicates that extensive training is required for novice surgeons to overcome the difficult vision–motion

| Table 1. Demographics for Novice and Experienced Laparoscopic and Endoscopic Surgeons |
|---------------------------------|---------------------------------|
| Novices                        | Experienced Laparoscopic and Endoscopic Surgeons |
| Number of participants         | 5                                      | 5                                      |
| Male:Female                    | 3:2                                    | 4:1                                    |
| Mean age (standard deviation)  | 27 ± 4                                  | 38 ± 8                                 |
| Number of years performing laparoscopic surgery (range) | 0-3                                      | 5-20                                   |
| Number of laparoscopic or endoscopic procedures performed per year | 0-10                                     | ≥100                                   |
There are a number of limitations related to this study. The first limitation was level of task complexity. A true endoscopic procedure requires an operator to combine multiple complex strategies to achieve successful performance of a surgical task. These maneuvers require more endoscopic skill than is required for the maneuverability and pointing task used in this study.

The second limitation was the number of surgeons required to perform the task. During NOTES procedures, it is common for at least 2 surgeons to work in a dyad team. Based on the analysis performed in this study, we have expanded our research efforts to incorporate bimanual coordination tasks and have begun to study the effects of mental workload of 2 surgeons working side by side on NOTES simulation models. In this new paradigm, 1 surgeon controls a dual-channel endoscope, whereas the other surgeon manipulates instruments on the surgical site. Replication of the current study with this new model will help improve the generalization of our findings to a clinical setting.

The third limitation was in the measurement used in the study. Time to completion was used to describe the observable impact of visual-motion malalignment on the task performance. In any goal-directed movement, such as the task that was incorporated into this study, there is a period of cognitive processing before the observable action, where environmental information is processed and an appropriate movement is planned.\textsuperscript{12} This cognitive process is more sensitive to the visual-motion alignment condition rather than execution of the chosen movement plan. A superior measurement for the cognitive process would be the reaction time, defined as the time from the moment where visual information is presented to an operator to the moment when a movement is performed.\textsuperscript{13} Future studies on the human factors of NOTES procedures will incorporate measurements of reaction in order to give a comprehensive description of the impact of visual-motion malalignment on surgeons’ performance.

In conclusion, the retroflexed-view condition in NOTES procedures using an endoscopic platform has a negative impact on the surgeon’s performance. Careful planning is suggested when selecting an appropriate approach, to avoid image retroflexion. Extensive endoscopic training is recommended for general surgeons before they can perform NOTES procedures safely and effectively.

**Authors’ Note**

The material from this manuscript was presented at the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR) annual meeting, held in San Francisco, CA, from July 7 to 8, 2008.

**Declaration of Conflicting Interests**

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