Distance Education System for Teaching Manual Skills in Endoscopic Paranasal Sinus Surgery Using “HyperMirror” Telecommunication Interface

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ABSTRACT

We have developed a distance education system for developing skills in endoscopic paranasal sinus surgery, to enable efficient remote training of novices in manual skills such as their standing position and posture, and the insertion angle/depth and holding of surgical instruments. The system uses a precise model of human paranasal sinuses and the “HyperMirror” (HM) telecommunication interface. HM is a virtual mirror allowing clear visualization of differences in manual operation between the trainee and remote expert. This paper outlines the proposed system and describes remote training experiments between two locations 200 miles apart. In the experiments, two expert surgeons trained 17 novices for 40 to 60 min on probing of the nasofrontal duct and aspiration of the maxillary sinus, and subjectively evaluated their manual skills. The results showed that most of the novices improved their manual skills and were able to complete each procedure.

KEYWORDS: Endoscopic sinus surgery, manual skill, remote training, surgical education.

INDEX TERMS: H5.1 [Information Interface and Presentation]: User Interfaces – Screen design; J3 [Computer Applications]: Life and Medical Sciences - Health; K.3.1 [Computer and Education]: Computer Uses in Education – Distance learning

1 INTRODUCTION

Endoscopic surgery requires a higher level of surgical skills than conventional methods. Since the field of operation cannot be seen with the naked eye and curved surgical instruments are used, such surgery requires sophisticated hand-eye coordination that cannot be acquired without repeated practice. Endoscopic surgery is dangerous if surgeons perform it before developing their hand-eye coordination and related skills. For example, ninety percent of complications have been predicted to occur during a surgeon’s first 30 cases in the case of laparoscopic cholecystectomy [1]. Support is therefore important at the early stages of learning.

We have been studying a system for training novices in endoscopic paranasal sinus surgery (ESS). This type of surgery is performed by inserting surgical instruments, such as an endoscope and forceps, through the nostrils without incision of the gingiva, which is required in conventional surgery. Particularly since the paranasal sinuses (Fig. 1) have an extremely complex structure and are adjacent to important internal organs, such as the optic nerve, brain, and arteries, separated by thin bone walls, sufficient training in the relevant skills is essential. However, the training environment for ESS novices is deficient because cadaveric training is limited in Japan and other countries and no appropriate animal model is available.

So far, we have developed an operable nasal model of the human paranasal sinuses as a patient model [2], and examined how surgical techniques of experts differ from those of novices by equipping the model and surgical instruments with sensors [3]. The results showed that the cause of the inability of young surgeons to manipulate instruments correctly with the same contact force as experts lies in basic manual skills such as their standing position and posture, and the insertion angle/depth and holding of the surgical instruments. We therefore determined that, among surgical skills, training should first be provided in physical skills, which we refer to as manual skills.

Conventionally, surgical skills have mainly been developed by the one-to-one teaching method under a supervising doctor and/or self-taught using textbooks and video instructional materials. However, it is difficult to acquire manual skills involving three-dimensional operations using such self-teaching materials, and although one-to-one instruction by experts is effective, there are limited opportunities for such instruction.

We have therefore proposed a distance education system for ESS, applying the “HyperMirror” (HM) telecommunication interface [4] and an operable nasal model as a patient model [2], which serves as a system for efficient instruction in manual skills such as standing position and posture, and insertion angle/depth and holding of surgical instruments, between remote locations.

HM consists of a pair of monitors that display, to both the trainee and trainer, mirror images produced by compositing and horizontally flipping images of the participants in remote locations. HM functions as virtual mirrors showing the participants side by side. The use of HM for distance training makes it possible for a trainer and a trainee in remote locations to compare re-
pective operations using a patient model of identical shape, allowing the trainee to smoothly imitate the trainer’s operations and the trainer to smoothly correct the trainee’s operations.

In this study, we developed a prototype of our proposed system and performed a remote training experiment between two locations 200 miles apart. This paper reports the results of our investigation into the effectiveness of this system.

## 2 RELATED STUDIES

In manual skills training, it is important to clearly show the differences in skills between an expert and a trainee. One intuitive and widely applicable method for this purpose employs a mirror. In various fields such as dancing, sports, etc., a trainer and trainee commonly practice side by side in front of a mirror so that differences in their posture are effectively fed back, thereby facilitating learning. Manual skills training systems using a virtual mirror based on virtual reality (VR) technology include a guitar training system developed by Motokawa et al. [5]. In this system, a monitor serving as a virtual mirror displays an overlaid view of mirror images of the trainee playing the guitar and a computer graphics (CG) image of a model, enabling the trainee to imitate the model. Another manual skills training system is a piano training system developed by Hikawa et al. [6]. Although this system does not use the concept of mirroring, it enables comparison of images of hands between a trainee and a model by projecting images of the trainer’s fingers onto the keyboard. However, since these methods show the differences in skill between a trainer and trainee by respective images seen from a single direction, they are inapplicable to manual skills training using a three-dimensional concept.

Our proposed system is designed to achieve three-dimensional training of manual skills (standing position and posture, insertion angle/depth and holding of surgical instruments, etc.) in endoscopic surgery by displaying images of the trainee and trainer from different directions, using two HMs.

## 3 METHODOLOGY

### 3.1 Distance Education System

#### 3.1.1 Overall Configuration

A prototype distance education system (Fig. 2) was installed at two locations 200 miles apart: Kanazawa and Tsukuba, Japan. The system consisted of two sites equipped with almost the same configuration of apparatus, allowing mutual exchanges of images and sounds via the Internet. A trainer and a trainee engaged in remote training by viewing endoscopic images and two HM images while operating on a nasal model of identical shape. During the experiment, images on the four monitors were incorporated into one image and video-recorded together with sounds.

#### 3.1.2 Endoscopic Image Monitors

The two upper monitors (15-inch; Model LC15S4, Sharp Corp., Japan) among the four monitors installed at each site displayed endoscopic images produced by the trainee and the trainer. In endoscopic surgery, securing the visual field is of primary importance; i.e., stable focusing of the site to be operated on at the center of the endoscopic image, maintaining the up-and-down directions of the endoscopic image, etc. The trainee confirms whether the proper visual field is secured by comparing his/her own endoscopic image with that of the trainer. Since the patient model for the trainee to operate on has the same shape as the trainer’s model, as long as the trainee manipulates the endoscope in the same way as the trainer, he/she can obtain exactly the same visual field. When the trainee’s endoscopic image differs from that of the trainer, the trainee can realize that his/her manipulation of the endoscope differs from the trainer’s.

#### 3.1.3 HM Monitors

The two lower monitors were HM screens for comparing the posture and the direction and depth of insertion of the endoscope between the trainee and the trainer. The lower-left monitor (21-inch; Model LC20S4, Sharp Corp., Japan) displayed a HM image (Fig. 3, left) obtained as a composite and a flip of the images of the trainee and the trainer captured from the front using a CCD camera (CSC680, Pacific Corp., Japan). This HM image makes it easy to compare an operator’s posture (including the standing position, direction of the body, angles of the arms, etc.) against the patient model and the directions of insertion of the endoscope.

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**Fig. 2 Prototype distance education system for endoscopic paranasal sinus surgery**

**Fig. 3 Composite of HM image**
The lower-right monitor (21-inch; Model LC15S4, Sharp Corp., Japan) displayed a HM image (Fig. 3, right) obtained as a composite and a flip of the images of the fingers of the trainee and the trainer captured from the right side using a video camera (Model NV-GS 100K, Panasonic Corp., Japan). This HM image enables comparison of angles and insertion depths in the back and forth directions of the endoscope and holding of the instrument.

The composites required to generate HM images were produced using chroma keyers (Model DCK500, Sony Corp., Japan, for the front monitor as well as the trainee’s endoscope monitor at the Tsukuba site; Model Tinga 1000P, Nihon Brain Ware Corp., Japan, for others). Since chroma keying was performed using blue as the key color, a blue background was selected for the Tsukuba site. To flip front images and right-side images, the flip functions of the CCD camera for capturing front images (CSC680, Pacific Corp., Japan) and the right-side HM monitor (Model LC15S4, Sharp Corp., Japan), respectively, were used.

3.1.4 Function of Indications by Trainer within Trainee’s Endoscope

In conventional one-to-one instruction, a trainer frequently explains anatomical structure while indicating a trainee’s endoscopic image and gives instructions in surgical operations. Thus, our system includes the function of providing such indications. The trainer’s indicative operations were captured with a small CCD camera (Model CK-300B, Keyence Corp., Japan) and the images were composited into the trainee’s endoscopic images. Composites were generated with a chroma keyer (Model DCK500, Sony Corp., Japan, at the Tsukuba site; Model Tinga 1000P, Nihon Brain Ware Corp., Japan, at the Kanazawa site).

3.1.5 Sound and Video Transmission

Sound and video in the remote training were transmitted using a videoconferencing system supporting the H.264 video compression standard (Model PCS-G70, Sony Corp., Japan; capable of simultaneous transmission of two images; used for transmission of endoscopic images, front images, and sound) and videoconferencing software (operated with iChat, Apple Inc., USA, and Apple Power Mac G4 or the like; used for transmission of right-side images and images of the trainer’s instructions). A microphone speaker system equipped with an echo canceller function (PJ100UH, Yamaha Corp., Japan) was used to prevent howling during hands-free conversation. The systems at the Kanazawa site and the Tsukuba site were connected via the FLET’S Hikari Premium broadband service of Nippon Telegraph and Telephone West Corporation (Kanazawa site) and the Science Information Network [7] (Tsukuba site). During the experiment, the maximum transmission rate was about 6.4 Mbps.

3.2 Subjects

An experienced surgeon at the Kanazawa site trained six trainees at the Tsukuba site (TS trainees: three fifth- and sixth-year medical students and three engineering students). An experienced surgeon at the Tsukuba site trained 11 trainees at the Kanazawa site (KS trainees: all fifth-year medical students). None of the trainees (nine males and eight females) had experience in ESS.

3.3 Learning Tasks

The following two types of surgical operations were set as the learning tasks in this remote training:

Task A: Probing of the nasofrontal duct with strongly and weakly curved Nishihata forceps (Fig. 4 (1))—the task of touching with the tip of the forceps, which had been inserted through the nostril, the opening of the nasofrontal duct communicating with the nasal cavity and frontal sinus.

Task B: Aspiration of the maxillary sinus with a curved suction tube (Fig. 4 (2))—the task of introducing the tip of the suction tube, which had been inserted through the nostril, into the maxillary sinus through the opened membranous part (i.e., the boundary between the nasal cavity and the maxillary sinus; a nasal model was used in which the membrane part had been opened), and then moving the tip as if stroking the inside. To see the maxillary sinus in the lateral nasal cavity, the trainee had to rotate the endoscope (Fig. 4 (3)) to obtain an outward view.

3.4 Experimental Procedures

After outlining the experiment and obtaining the subjects’ consent, we conducted the experiment using the following procedures.

3.4.1 Pre-experiment Trials

First, the trainees watched a video (about 4 min) explaining how to use the surgical instruments. For each of task A and task B, after watching another video (about 7 min for task A; about 5.5 min for task B) explaining the anatomy of the site to be treated and the task, the trainees were asked to perform the task within 3 min (hereinafter referred to as the measuring task).

3.4.2 Remote Training Trials

The TS trainees and KS trainees participated in the training trial two times and three times, respectively, over a period of two days in both cases. In the first training trial, the trainees watched a video (about 7 min) explaining how to use the system. In each training trial, for each of task A and task B the trainees received a 10 min remote training and then performed the measuring task.

The trainer watched the same videos explaining each task and how to use the system as the trainees had seen. The trainer was asked to provide instruction in the same surgical operations as shown in the videos, but the specific instruction method was left to the trainer’s discretion.

3.4.3 Post-experiment Trials

For each of task A and task B, the trainees performed the measuring task after watching a video (about 4.5 min) explaining it.

3.5 Assessment of Trainees’ Surgical Operations

Based on video observation of the trainees’ measuring tasks, the trainer at the Tsukuba site subjectively evaluated whether or not each trainee had been able to complete the tasks and to what degree he/she had been able to perform operations of the surgical instruments on a 5-point scale.

4 Results

Figure 5 shows the results of the evaluations of the measuring tasks in the pre-experiment trial and post-experiment trial.

5 Discussion

As a result of the remote training, many of the trainees acquired operation skills for tasks A and B. Three-dimensional operations entailing view transformation with the endoscope, using curved surgical instruments, have been extremely difficult to master by trial and error and remote training with verbal explanations alone. Hence, the trainees are considered to have mastered the operation skills for task A and task B effectively using both the trainee’s and trainer’s endoscopic images in addition to the front and right-side HMs.

Specifically, the remote training sessions were observed in which the trainers and the trainees compared and imitated: (a) the
standing position and posture by watching the front HM, (b) holding of the surgical instruments and the angle and depth of their insertion by watching the front and right-side HM, and (c) endoscopic images by watching the trainee and trainer endoscope monitors. The function by which the trainer provided indications within the trainees’ endoscopic images (see 3.1.4) was as effective as in conventional one-to-one instruction.

This system was also the trainers’ first experience in such an instruction environment, and they identified effective instruction tactics during the training sessions. The following were considered to be particularly important.

1. The trainer clearly indicates tips and corrections in surgical operations by gestures after pointing them out verbally.
2. When demonstrating a model operation for the trainee to perform, the trainer waits until the trainee can understand the operation of the trainer well enough to imitate it.
3. The trainer reproduces inappropriate postures and instrument operations produced by the trainee and shows the process of correction to the appropriate posture and operation.

These points should be considered when materials and curricula for self-teaching are prepared.

The TS trainees achieved lower scores than the KS trainees (although the difference was not significant). This is probably because the KS trainees received the remote training three times, whereas the TS trainees received it only twice. Further, task B produced lower scores than task A (again, the difference was not significant). This is mainly because task B was a difficult task involving rotation of the oblique-view endoscope. Another problem with task B was the low resolution of the front HM, hindering the trainees from clearly seeing how to hold and manipulate the instruments. There is room for improvement in this area, such as by providing zoom-up images of the hand.

This system can also serve as a self-teaching system by using playback images instead of live images of a trainer. The self-teaching system is expected to enable repeated practice at a low cost and is thereby better suited for skill acquisition by novices.

6 Conclusion
We have developed a distance education system for surgical techniques in ESS, specifically aimed at providing effective training in manual skills to novices, and demonstrated its effectiveness in remote training experiments. The use of HyperMirrors in the proposed system allows a trainee to compare his/her surgical operations with those of a trainer and to imitate the trainer’s operations, thus enabling one-to-one instruction between remote locations in manual skills such as the standing position and posture, and insertion angle/depth and holding of surgical instruments.

In the future, we would like to evaluate the proposed system more quantitatively by comparing it with conventional training methods. In addition, we would like to develop a self-teaching system that has the function of automatically judging manual skill levels, instruction curricula, and self-teaching materials. Through such research, we will adapt our technology to the medical education field and thereby contribute to the improvement of safety in surgery and the alleviation of regional disparities in medical care.

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References

![Fig. 4 Surgical instruments: (1) Nishihata forceps, strongly and weakly curved; (2) Curved suction tube; (3) 4 mm 30 deg oblique-view nasal endoscope.](image)

![Fig. 5 Effect of remote training: (1) percentage of subjects able to complete the task; (2) degree of achievement (boxes indicate median and interquartile ranges; whiskers indicate largest and minimum values). The trainer at the Tsukuba site subjectively evaluated on a 5-point scale to what degree the trainees had been able to perform operations using the surgical instruments (task A: endoscope and Nishihata forceps, strongly and weakly curved; task B: endoscope and suction tube), and obtained the average for each subject. Wilcoxon signed rank test: * P < .05, ** P < .01, *** P < .001.](image)