Using a high-definition stereoscopic video system to teach microscopic surgery

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ABSTRACT

Introduction: While there is an increasing demand for minimally invasive operative techniques in Ear, Nose and Throat surgery, these operations are difficult to learn for junior doctors and demanding to supervise for experienced surgeons. The motivation for this study was to overcome teaching obstacles during microscopic surgical training by the use of high-definition (HD) stereoscopic video monitoring.

Material and methods: We attached a 1280x1024 HD stereo camera (TrueVisionSystems^{TM} Inc., Santa Barbara, CA, USA) to an operating microscope. The stereoscopic live image was displayed by two LCD projectors @ 1280x768 pixels on a 1,25m rear-projection screen by polarized filters. While the junior surgeon performed the surgical procedure based on the displayed stereoscopic image, all other participants (senior surgeon, nurse and medical students) shared the same stereoscopic image from the screen.

Results: Fine adjustments required about 10 to 15 minutes before each operation. Five major effects were obtained: A) HD resolution avoided the need for direct look through the microscope's binocular tubes. B) Stereoscopy facilitated orientation for the junior surgeon as well as for medical students. Stereoscopy helped the junior surgeon specifically to find the correct surgical plane. C) The stereoscopic image served as an unequivocal guide for the senior surgeon to demonstrate the next surgical steps to the junior colleague. D) The theatre nurse shared the same image, anticipating the next instruments which were needed. E) Medical students instantly share the information given by all staff and the image, thus avoiding the need for an extra teaching session.

Conclusion: In this context, for the first time stereoscopic video in high definition resolution has been used to replace direct microscopic view to perform surgical interventions in Otorhinolaryngology. The system bears the potential to compress the learning curve for undergraduate as well as postgraduate medical professionals in minimally invasive surgery. Further studies will focus on the long term effect for operative training as well as on post-processing of HD stereoscopy video content for off-line interactive medical education.

Keywords: Medical education, Otorhinolaryngology, Stereoscopy, Postgraduate Training, Microsurgery

1. INTRODUCTION

In many surgical specialties, manipulating small structures is a task that is routinely performed during operative procedures. Additionally, pathways through which this task is performed are generally small (e.g. the outer ear canal for reconstructive middle ear surgery) and tend to get smaller for the benefit of a better cosmetic result (i.e. minimal incision in cochlear implantation). The whole range of reconstructive microsurgery, enabling the surgeon to restitute hearing in Otology or eyesight in Ophthalmology or removing pathologic tissue with minimal disruption to normal function such as in Neurosurgery has only become possible with the introduction of operating microscopes to surgery in the early 1950's. Since then, generations of junior surgeons have been trained in microscopic surgery not only to pass on standard microsurgical procedures but also to continuously refine surgical techniques. However, for junior surgeons acquiring knowledge about surgical procedures and manipulative skills can be a time-consuming and difficult process. In contrast to open surgery, where junior and senior surgeon see the same operative field without any optical aid and interact frequently by swapping the roles of operating and assisting surgeon, microsurgery largely depends on the quality of image seen by both surgeons by means of a microscope. Microscopes, however, are usually optimized for single user

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operation in terms of stereo view, field of vision, brightness and focus. They require a monocular or binocular teaching device attached laterally to a beam-splitter, which delivers a monoscopic image that corresponds to either the left or right eye's view of the surgeon. Thus the assisting surgeon's field of view and his depth perception is different from the operating surgeon's. While it has been shown that senior surgeons can translate a monoscopic image into correct perception of the operative site due to their experience from anatomic proportions, the problem for junior doctors is that visual information delivered by a monocular is incomplete and can be puzzling. Once the junior surgeon gets his opportunity to acquire hands-on experience, the challenging change to binocular vision is doubled by the challenge to perform surgical tasks with less developed manual skills. On the other hand, the senior surgeon cannot actively intervene with the junior surgeon's performance, limiting his guidance to verbal communication. Thus, in order to complete the operation safely, the senior surgeon takes over at an early stage, leaving his junior counterpart again with a passive role.

There are two major factors which fuel the need to overcome these obstacles in teaching: First, the relative figure of microsurgical procedures is increasing in relation to open surgery: Of 2048 operative procedures within a one-year-period at our department, 47.8% were performed using a microscope and further 6.7% using a rigid endoscope, while 45.5% did not require any optical device. Although the preference for either an endoscope or a microscope may vary from department to department, it can be assumed that the number of operations without optical device is fairly constant. Second, the economic pressure exerted on surgical departments requires efforts to increase the level of surgical skills over the whole medical staff within a shorter period of time. Thus, a teaching system that bears the potential to compress the learning curve for junior surgeons is desirable.

From two earlier publications[1,2], we could show that in medical education depth perception can be enhanced by displaying stereoscopic video content to medical students of personal stereoscopic displays (i.e. CRT monitor with shutter glasses, LCD monitor with polarized filter screen in conjunction with polarized filter glasses or by means of autostereoscopic displays). Although multimedia teaching cannot replace hands-on experience in direct contact with patients, in many cases physical presence in theatre is no longer necessary to understand the idea of surgical concepts that are designed to remove pathology and preserve intact structures plus restore function[3,4].

From these earlier results we concluded that a stereoscopic image displayed in high resolution on one large screen could be able to facilitate orientation for the junior surgeon so that the right surgical plane is found and maintained while image resolution is still comparable to the original optical image. This study was conducted to demonstrate the use of a high definition stereoscopic video camera system for postgraduate training of junior doctors and education of medical students in otorhinolaryngologic, microscopic surgery.

2. MATERIALS AND METHODS

The high definition microscopic stereo video camera system ("Stereoscopic Vision System", TrueVisionSystems™ Inc., Santa Barbara CA, USA) consists of a stereo video camera head with a maximum resolution of 1280x1024 pixels. This camera head is fitted with a standard mounting bracket for Zeiss operation microscopes. The camera head is connected to an image processor computer (PC Workstation, double processor Intel® Xeon® CPU, 3.0 GHz, 1024MB RAM; Intel Co., Santa Clara, CA, USA). The computer's output connects to a set of two LCD display screens (Planar Systems Inc, Beaverton, OR, USA) via two separate DVI-D connectors which deliver the signal for left eye / right eye display.

The video signal passed to two standard LCD projectors with 1280x720 pixels resolution (Sharp Co., Tokyo, Japan) which are built into an adjustable metal frame to allow proper alignment of both (left and right) images. Again, both projector images are coded for left eye / right eye perception with polarized filter glasses in front of each projector lens (left eye: top left to bottom right and right eye: bottom left to top right). Both images are displayed on a non-depolarizing rear-projection screen with 1.25m in diameter.

In an operating theatre (Fig. 1), the binocular tube of an operating microscope ("Zeiss OpMi ProMagis", Zeiss Co., Oberkochen, Germany) is replaced with the stereo video camera head. For practical reasons, the LCD projector set in conjunction with the rear-projection screen is preferred to the single-user LCD monitor set, as it allows multi-user operation. The screen is set up to the right hand side of the patient in about 1.40 m distance from the operating surgeon.

All participants (operating surgeon, assisting surgeon, theatre nurse, and medical students) wear polarized filter glasses which decode both images for stereo perception. The patient's position and surgical procedure itself are not altered in any way compared to conventional microscopic surgery.

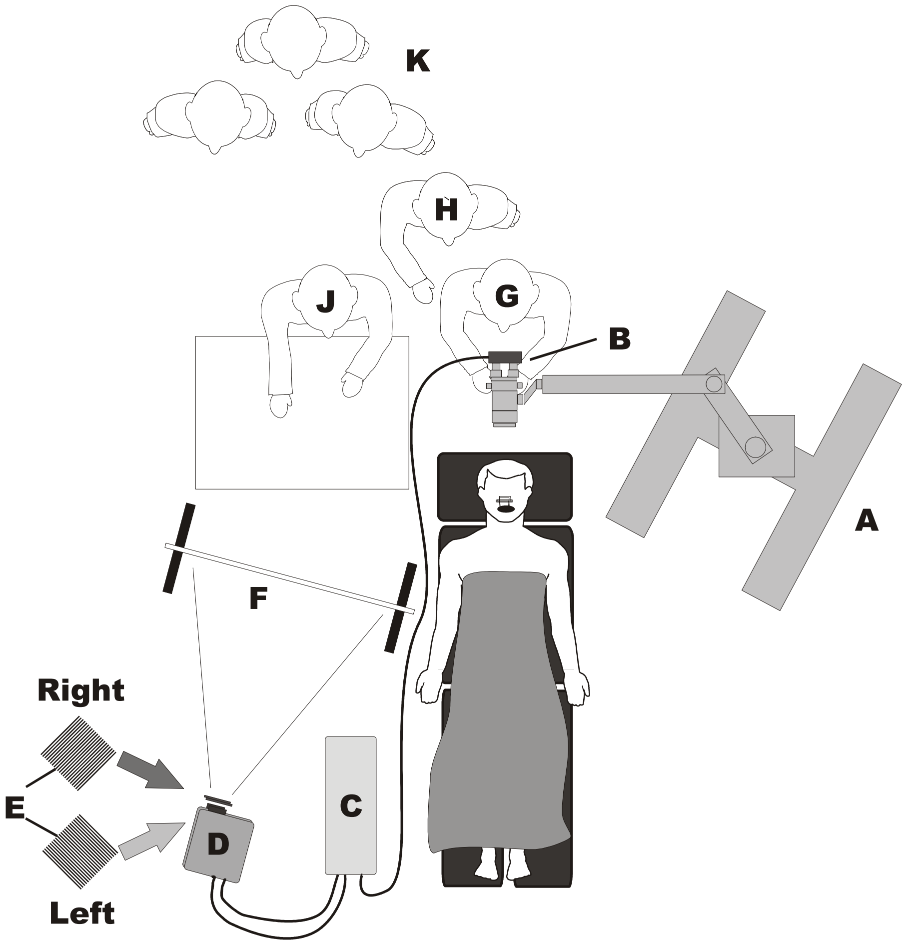

Fig. 1: General set-up in the operating theatre during microscopic laryngeal surgery: a) microscope, b) HD stereo camera head, c) stereo image processor workstation, d) stack of two LCD Projectors, e) orientation of polarized filters in front of each LCD projector lens, f) rear-projection screen g) operating surgeon, h) assisting surgeon, j) theatre nurse, k) medical students

3. RESULTS

General setup of the system in conjunction with the displays or the LCD projectors had to be performed only once. This task required about 20 minutes and was performed outside the operation theatre. Given the modular construction of Zeiss operation microscopes, no alignment of the stereo camera head to the operation microscope was needed. However, setting up the rear-projection screen and adjusting the position of the LCD projectors inside the operation theatre required another 10 to 15 minutes. As the patient has to be taken on and off the operation table, this procedure had to be repeated before each operation. The theatre nurse had to change his / her position from the patient's right hand side facing the surgeon to a place at the right hand side of the operating surgeon, facing the patient (Fig. 1, pos. "J"), as the former position is taken in by the rear-projection screen. However, this enables the nurse to watch the whole surgical procedure from the screen, whereas under conventional microsurgery, the nurse would have to work on the surgeon's verbal orders.

Fig. 2: Operation theatre site during surgery. The rear projection screen (*) displays the stereoscopic image projected by two LCD projectors (not in picture) and is watched (left to right) by three medical students (background), the theatre nurse and the assisting surgeon.

Given the size of the screen, operating (junior) surgeon and assisting (senior) surgeon, theatre staff and up to five further 4th year medical students are able to follow the operation stereoscopically in HD resolution watching the same projected moving image (Fig.2). In contrast to LCD displays, the viewing angle did not affect stereoscopic depth perception to about 55° off the central axis to either side. The time to experience stereoscopic vision was less than one and up to 5 seconds maximum and did not depend on the use of contact lenses or spectacles. The experienced (assisting) surgeon directed the junior (operating) surgeon in a step-by-step approach to perform various operative tasks by pointing at the rear-projection screen (Fig. 3). Thus the junior surgeon could perform the whole procedure without swapping his position with the senior surgeon at any stage. It was noted that none of the junior surgeons experienced difficulties in finding the right surgical plane, although secondary clues (such as a blurry image in distal or proximal planes) were kept to a minimum by closing the camera's diaphragm. Junior surgeons specifically noted that stereoscopic perception helped them to find the surgical plane as their practical knowledge of anatomic proportions in a longitudinally oriented organ as the larynx were not yet finally developed. Furthermore, instrumentation was facilitated as the nurse always followed the operation and therefore anticipated the instruments which were needed next. Although the direct image from the microscope's binocular tube is still more detailed, the system's high definition resolution comes much closer to reality than conventional PAL or NTSC video resolution. Visual fatigue was noted by one of five medical students after about 10 minutes. This was overcome by taking off the polarized filter glasses and looking at visual clues in the operation theatre for about 30 seconds.

Fig. 3: Operation theatre site during surgery as in Fig. 2. The assisting senior surgeon (right) directs the operating junior surgeon (left) by the displayed stereoscopic image on the rear projection screen (*) while the theatre nurse (middle) follows the operation. The stereoscopic camera head is attached to the operating microscope instead of the set of binocular tubes (arrow).

4. DISCUSSION

To the best of our knowledge, in our study stereoscopic video in high definition resolution has been used to replace direct microscopic view to perform surgical interventions in Otorhinolaryngology for the first time. Stereoscopy devices have been used in the operation theatre before, either as a standalone solution or in combination with three-dimensional volume rendering from computer-assisted surgery[5,6]. However, these devices have rarely served as the main source of visual information for the surgeon, as their resolution is limited. In rigid or flexible endoscopy, the image is often delivered by a standard definition TV monitor which displays a monoscopic image whose resolution is limited to either PAL (720x576 pixels) or NTSC (720x480 pixels) standard. While this resolution is sufficient for flexible endoscopy, the resolution loss from the original image of a microscope or rigid endoscope is substantial.

There have been few reports on the evaluation of stereoscopy in surgery. Von Pichler and co-workers noted that in their study on a laparoscopic model, stereoscopy made no difference to the operation time of an experienced surgeon, although it facilitated orientation and reduced operation time for inexperienced surgeons effectively compared to monoscopic vision[7]. Although the set-up of the system can be complex and requires all viewers to wear polarized filter glasses, the stereoscopic viewing impression is robust against position changes and the number of viewers. There are other stereoscopic display devices, which all have advantages as well as disadvantages. The combination of cathode ray tube monitors with shutter glasses is a widely proven method[8]. Its main drawback is the need for synchronization between the display and the glasses, either by a cable or an infrared link. Autostereoscopic displays avoid the necessity to wear glasses. However, the range of movement is extremely limited as there are only few defined positions in front of the screen to obtain a proper stereoscopic image. Infrared eye tracking is one method to adjust the stereoscopic viewing position to its spectator. However, in this case the number of viewers is limited to one.

The major advantage of the presented system is its ease of use for all personnel involved in the operation process. Once the polarized filter glasses have been put on, the depth impression in high definition resolution creates an image that comes close to the natural image seen through the binocular tubes of a microscope. The visual information is not exclusively given to the operating surgeon but to all staff standing in front of the screen. Thus communication between the junior and the senior surgeon is facilitated in the same way as interaction between the operating surgeon and the theatre nurse as well as for the senior (assisting) surgeon who can teach medical students at the same time without neglecting supervision of his junior colleague. The extra setup time required before the procedure is thus compensated by the ease of interaction and the accelerated workflow. However, this applies particularly to procedures which would need longer than one hour to perform. With shorter procedures, the extra time needed for setup would at present prolong procedures as a whole.

One of the disadvantages of the present systems is its size and the amount of data to be processed by the workstation which is in the range of 2Gbit/s, requiring a rather large PC workstation. However, with further advances in processor technology it should be possible to either create a fully mobile version or to install a stationary unit attached to the theatre wall.

The surgical procedures performed here were limited to laryngeal and tracheal surgery, as the access via the patient’s oral cavity is sufficiently wide. It has to be mentioned that microscopic paranasal sinus surgery and reconstructive middle ear surgery are more challenging. In paranasal sinus surgery the access via the human nostril is 1 to 2 cm² wide, while the distance between the tip of the nose to the posterior skull base is around 10cm. Thus the parallax, which is further enhanced by the use of retaining instruments that obstruct views off the central axis plus the limited depth of field impede stereoscopic vision in online teaching considerably. In microscopic ear surgery, distances in the range of a hundredth of a millimeter have to be respected in order to avoid a functionally unfavorable result. This includes observation of very discrete color changes of tissue, e.g. translucency of bony tissue in mastoid surgery which indicates proximity of the vestibular organ. Such minute changes may yet exceed the resolution and color differentiation of the system. In this context it would be desirable to attach the camera head to the operating microscope via a beam splitter rather than exchanging the binocular tube against the camera head. In an emergency such as camera failure, the surgeon could always rely on the conventional binocular tube image without unpacking the microscope from its sterile drapes.

If recorded, stereoscopic video content from live surgery is not self-explanatory. However, if combined in dedicated authoring media with three-dimensional volumetrically rendered models, the content can be used for a wide variety of purposes, i.e. undergraduate as well as postgraduate medical education, as a preparatory tool to ease the strain of using a microscope and maintaining orientation in less explored territory for junior doctors. Finally, informed consent by patients and caretakers can be facilitated by the same media with few adaptations.

POINTS FOR FURTHER DEVELOPMENT

- Construction of a mobile cart which contains all devices (projectors, computer and screen) in a pre-adjusted fashion, which can be stowed and installed as needed, thus avoiding extra time for pre-operative setup.
- Minimizing the image processing computer to e.g. laptop or desktop size, so modifications can be easily implemented
- Writing suitable compression / decompression algorithms, so the stereo image can be transferred online to seminar rooms, lecture halls etc. over an ordinary in-house computer network with a maximum capacity of 100Mbit/s
- Creating a high definition recording facility to capture stereo video content

- Post-production of video content[9] including stereoscopically rendered, 3D computer-generated models or volumetric projections of CT / MRI images
- Integrating all contents on DVD media for interactive off-line teaching media by suitable authoring systems

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