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Integrated Surgical Simulation and Navigation for Improved Patient Safety

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1. Introduction

Surgical treatment of disorders of the nose and the ear, as in endonasal sinus surgery or temporal bone surgery, usually involves intricate anatomy with various organs at risk which, when injured, may cause major complications. These include the eyes, facial, optic, and olfactory nerves, cranial base, sinuses, and internal carotid arteries. In the worst case, rupture of the latter may result in death of the patient.

The traditional approach to training residents is hands-on experience with live patients, complemented by training using cadaveric material. With this approach being limited for obvious reasons, virtual reality (VR) simulators which enable a resident to practice different surgical approaches are increasingly considered useful »Reznick and MacRae 2006«. They allow performing procedures with realistic visual and haptic feedback, based on virtual training cases.

In the last few years, a number of simulators for surgical procedures in otorhinolaryngology have been presented, which are mostly in prototype status »Fried et al. 2007«. This paper gives a short introduction to the concept of surgery simulation as developed in the VOXEL-MAN project. As a unique feature, this system may also be used with individual patient CT data for planning and rehearsal of especially complex interventions. Furthermore, this type of surgical planning can be combined with a surgical navigation system as used for image guided surgery (IGS), to make the planning results available in the operating room.

2. Materials and Methods

2.1. Modeling

For maximum realism, all virtual models are based on clinical CT data. From several hundred CT studies, about 5 were selected for temporal bone surgery and 3 for sinus surgery, which completely covered the region of interest and provided a high enough resolution to clearly show all relevant structures. From these data, several training cases were created as three-dimensional voxel models by interactive segmentation of the major structures such as bone, soft tissue, and organs at risk (e.g. nerves, arteries, veins). For segmentation, intensity thresholds were used, and the results manually edited as required. Results were stored as object membership labels of the voxels, and objects were described in a knowledge base, including anatomical terms in several languages »Pommert et al. 2006«.

2.2. Visualization

For 3D visualization, a high-resolution algorithm with subvoxel accuracy was used »Tiede et al. 1998«. The user sees the operating scene on one or more virtual cameras (macro-, micro- or endoscopic; optionally in stereo, using shutter glasses), and three orthogonal cross-sectional images which show the original CT data, corresponding to the position of the tip of the instrument. The whole system is implemented on standard PC hardware under Linux.

2.3. Handling

Interaction with the system is performed by moving the camera and using a set of virtual instruments. Motion of an instrument is controlled with a *Phantom Omni* force feedback device (SensAble Technologies, Woburn, MA, USA) with 6 degrees of freedom. For this purpose, an algorithm for haptic rendering of the voxel data was developed »Petersik 2007«.

For the different types of interventions, typical sets of instruments such as metal and diamond drills or cutting Blakesley forceps were designed and implemented as polygon models. As in reality, the trainee uses a foot pedal to control the virtual drills. For simplicity, opening and closing of the forceps, which is operated with a handle similar to a pair of scissors in reality, is simulated by pressing a button on the handle of the Omni. Removal of tissue is simulated in real time with an algorithm with subvoxel accuracy »Pflesser et al. 2002«.

2.4. Surgery Planning and Rehearsal

Besides the above mentioned training cases, the simulator may also be used with individual patient data for planning and rehearsal of individual procedures. In this case, the original CT images are imported with a DICOM reader, and the bone is interactively segmented with a lower threshold value. Since only bone is identified, soft tissue, organs at risk etc. are not represented in these models. For the patient cases, the same instruments as for the training cases are available.

2.5. Connection to a Surgical Navigation System

As a step further, we combine this type of surgical planning with a surgical navigation system commonly used in image guided surgery. For this purpose, a *VectorVision* navigation system (BrainLAB, Feldkirchen, Germany) was connected to our *VOXEL-MAN* surgery simulator, using the *VVLink* interface library »Neff 2003«. It allows to download CT data of the patient from the navigation system to the simulator, permanently reading the position of the currently used instrument, and sending back images to the navigation system control screen (figure 1).

3. Results

Using the above described methods, a family of surgery simulators for different fields of application could be developed:

– *VOXEL-MAN TempoSurg* for drilling access to the middle ear »Leuwer et al. 2008«
– *VOXEL-MAN SinuSurg* for endonasal sinus surgery
– *VOXEL-MAN DentalSurg* for apicectomy and preparation of partial crowns.

While the first is already available (Spiggle & Theis, Overath, Germany), the other two are in advanced and early prototype states, respectively.

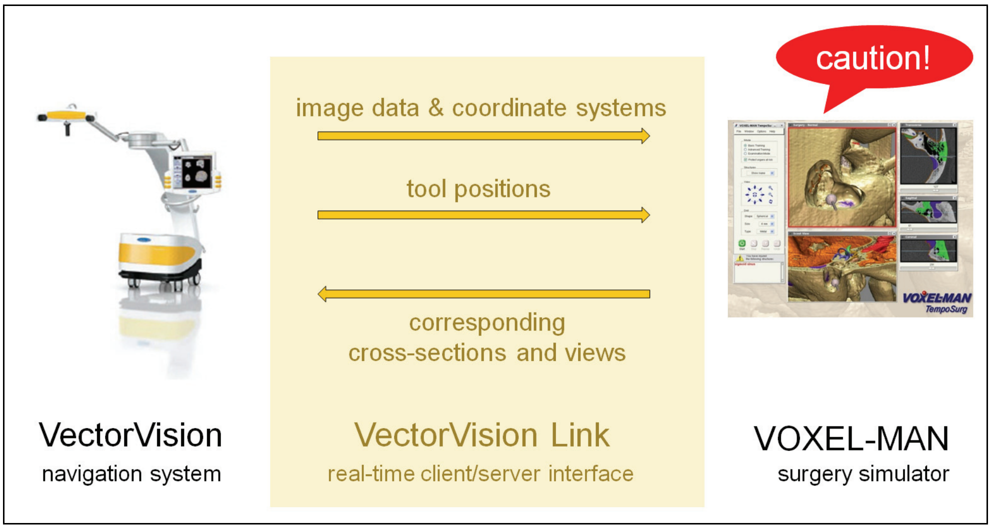

Figure 1: Integration of navigation system and surgery simulator.

For education, the trainee can choose between different training cases, providing different anatomical variations and pathologies. The trainee uses the Omni and a foot pedal to control the virtual instruments and wears shutter glasses for stereoscopic viewing. According to the movements of the instrument, the virtual scene is updated in real time.

A screenshot from a training session with *VOXEL-MAN TempoSurg* is shown in figure 2. The actual drilling of the temporal bone is performed in the large window at center, where the patient is seen positioned on the back of his head. The window below provides an additional view of the structures at risk. The panel at left allows for several basic adjustments, such as changing the view position or the virtual instruments. On the right, three orthogonal cross-sections are presented. Similar to a surgical navigation system, these cross-sections are displayed according to the position of the tip of the instrument. The tissue which has already been removed is marked in green. Whenever an organ at risk is injured, an alarm sounds and the name of the structure is written to a protocol. Success of a simulated intervention may thus easily be controlled.

A screenshot from a training session with *VOXEL-MAN SinuSurg* is shown in figure 3. This simulator allows very realistically working through a sequence of ethmoidal cells, or operating the other paranasal sinuses. As in reality, thin bones and mucosa may be cut away, ripped off, or punched through with the virtual instrument.

For planning and rehearsal of difficult cases, the surgeon can also import sequences of CT images and work on a virtual model of his patient, using very much the same instruments and techniques as in the real procedure »Tolsdorff et al. 2007«. As with the training cases, the model may be visually inspected and manipulated on 3D views, and controlled on additional cross-sectional images.

Since the tissue removed during planning provides a perfect description of the safe workspace for actual surgery, it is a natural step to make this information available in the operating room, using the above described connection to a surgical navigation system. During surgery, the images from the planning (both 3D views and cross-sectional images, with the removed tissue color-marked) may be inspected on the screen of the navigation system, according to the position of the real instrument (figure 4). When the workspace is left, an alarm sounds.

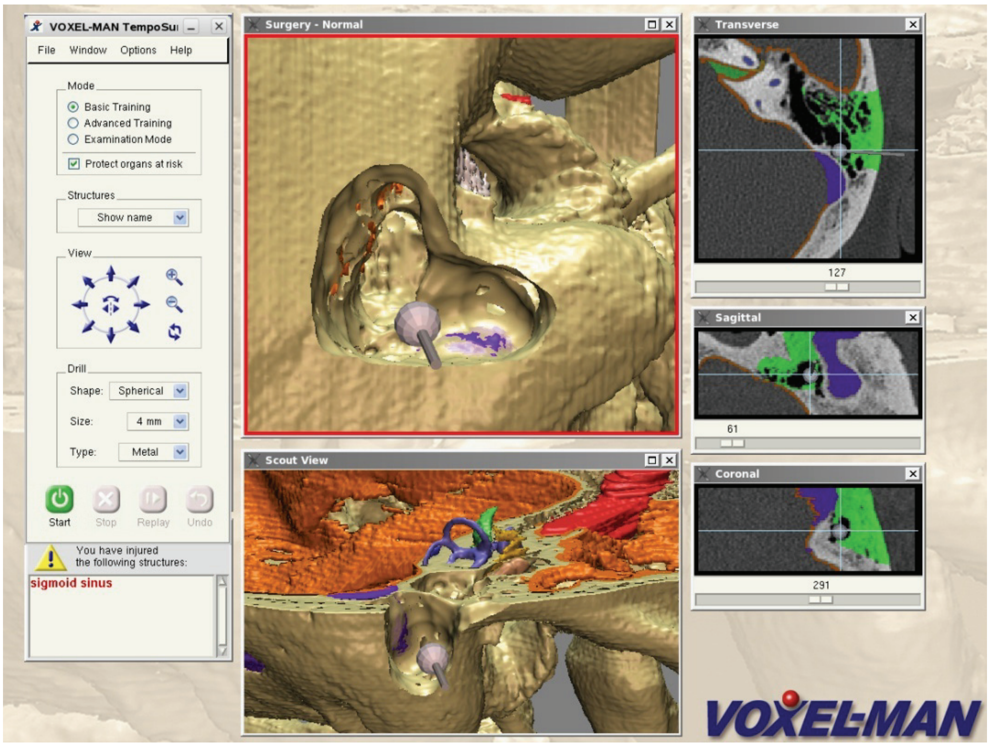

Figure 2: Screenshot of VOXEL-MAN TempoSurg. The trainee has already opened a large part of the temporal bone. On the cross-sectional images (right), the already removed tissue is marked in green.

4. Conclusions

In this paper, we presented the *VOXEL-MAN TempoSurg* and *SinuSurg* virtual reality simulators for otolaryngology. These systems may be used for education as well as for surgical planning and rehearsal. To our best knowledge, *VOXEL-MAN TempoSurg* is the first stable, fully operational simulator in this field available on the market.

This kind of simulators opens up vast new possibilities for education. Unlike in reality or even in the bone drilling lab, the trainee has the opportunity to make and immediately correct mistakes. From an educator's point of view, a standardized curriculum with controlled tasks, anatomical variations, shape of pathologies etc. becomes possible.

In a recent study, it could be shown that the *VOXEL-MAN TempoSurg* simulator is appropriate for assessment of trainees at the transition from laboratory based training to operative practice »Zirkle et al. 2007«. In another study using a prototype of *VOXEL-MAN DentalSurg*, it was concluded that simulator based training for apicectomy appears to be effective, and the skills acquired are transferable to physical reality »Sternberg et al. 2007«. Although a simulator is certainly no substitute for operative experience with the complex preoperative decision making and planning, patient and microscope positioning, blood in the field etc., these results are certainly very promising.

For surgical planning, the presented approach provides several advantages: The surgeon can make a very realistic planning and rehearsal in advance, and has the resulting images available for comparison in the operating room. Since an alarm is issued when the previously planned path is left, he can fully concentrate on his work. With this combination of simulation and navigation, we believe difficult procedures can be made much safer in the future.

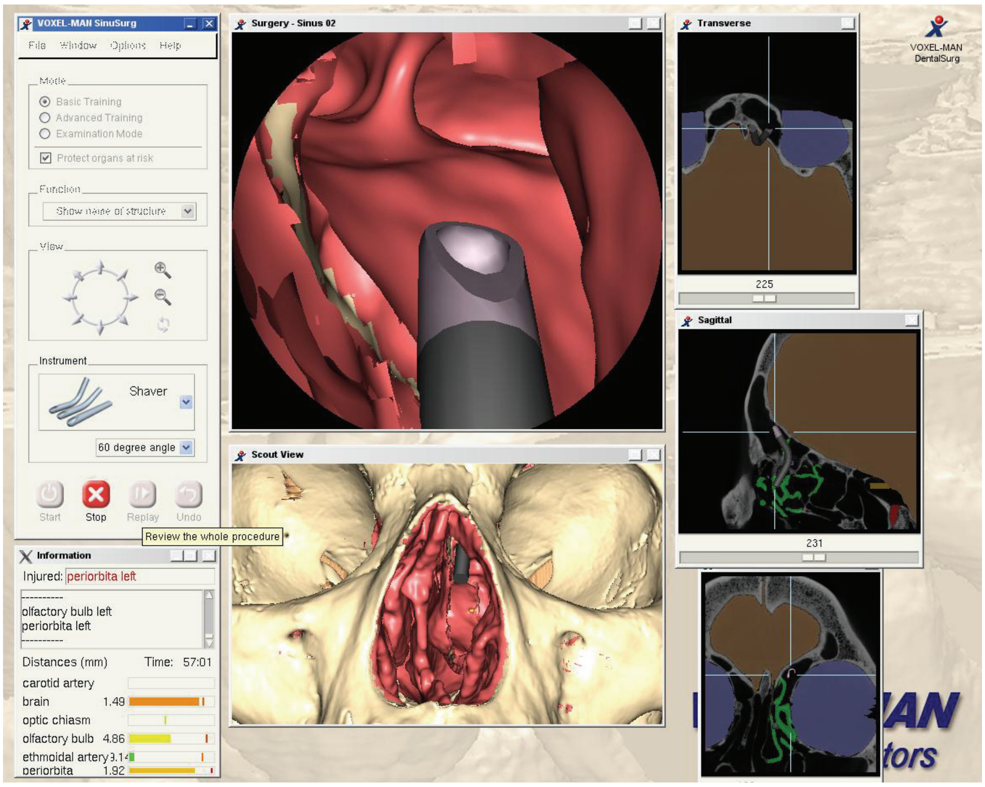

Figure 3: Screenshot of VOXEL-MAN SinuSurg. The trainee is working in the frontal recess using a shaver. The operating field is seen through an endoscope (top) and on an overview image (bottom).

5. References

Fried MP, Uribe JI, Sadoughi B (2007): The role of virtual reality in surgical training in otolaryngology. Current Opinion in Otolaryngology and Head and Neck Surgery 15 (3), 163-169.

Leuwer R, Petersik A, Pflesser B, Pommert A, Tolsdorff B, Höhne KH, Tiede U (2008): VOXEL-MAN TempoSurg: A Virtual Reality Temporal Bone Surgery Simulator. Head and Neck Surgery (Japan) 17(3), to appear.

Neff M (2003): Design and implementation of an interface facilitating data exchange between an IGS system and external image processing software. Diploma thesis, Technical University of Munich.

Petersik A (2007): Realistische haptische Simulation materialabtragender chirurgischer Eingriffe. Fortschritte in der Robotik Bd. 11. Shaker Verlag, Aachen.

Pflesser B, Petersik A, Tiede U, Höhne KH, Leuwer R (2002): Volume cutting for virtual petrous bone surgery. Computer Aided Surgery 7 (2), 74-83.

Pommert A, Höhne KH, Burmester E, Gehrmann S, Leuwer R, Petersik A, Pflesser B, Tiede U (2006): Computer-based anatomy: A prerequisite for computer-assisted radiology and surgery. Academic Radiology 13 (1), 104-112.

Reznick RK, MacRae H (2006): Teaching Surgical Skills — Changes in the Wind. New England Journal of Medicine 355 (25), 2664-2669.

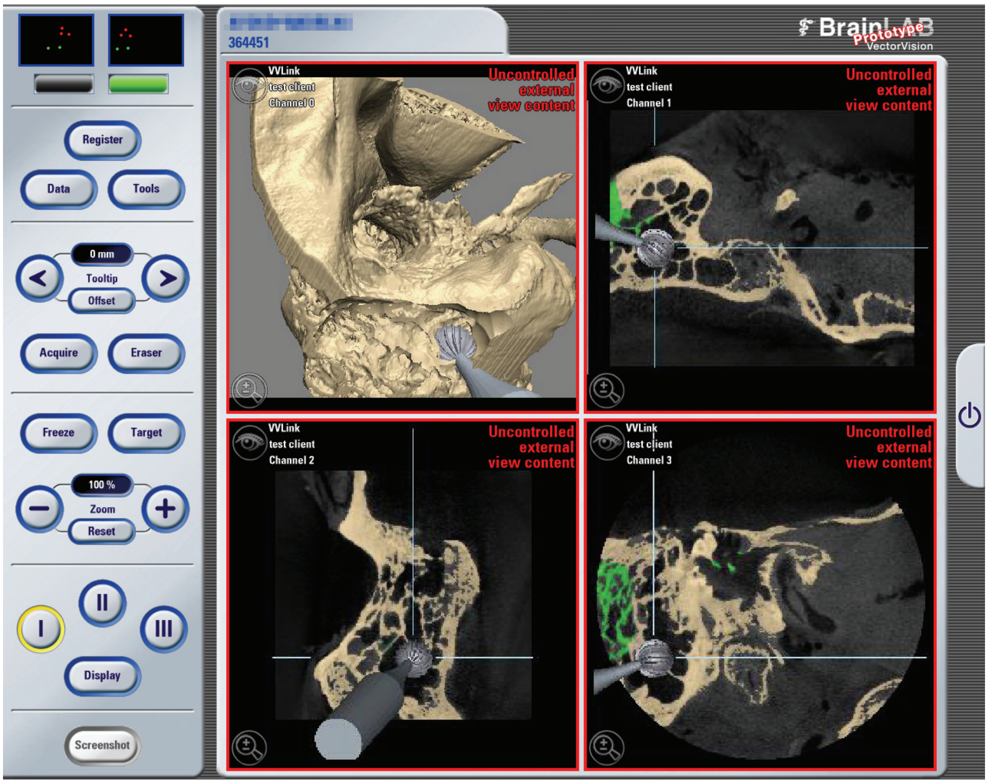

Figure 4: Screenshot of the VectorVision surgical navigation system, connected to the simulator. The 3D views and cross-sectional images uploaded from the simulator indicate the workspace as defined during surgery planning and rehearsal, and may thus easily be accessed in the operating room.

Sternberg N von, Bartsch M, Petersik A, Wiltfang J, Sibbersen W, Grindel T, Tiede U, Warnke P, Heiland M, Russo P, Terheyden H, Pohlenz P, Springer I (2007): Learning by Doing Virtually. International Journal of Oral and Maxillofacial Surgery 36 (5), 386-390.

Tiede U, Schiemann T, Höhne KH (1998): High quality rendering of attributed volume data. In David Ebert et al. (eds.): Proc. IEEE Visualization '98. Research Triangle Park, NC, 255-262.

Tolsdorff B, Petersik A, Pflesser B, Pommert A, Tiede U, Leuwer R, Höhne KH (2007): Preoperative simulation of bone drilling in temporal bone surgery. International Journal of Computer Assisted Radiology and Surgery 2 (Suppl. 1), 160-161.

Zirkle M, Roberson DW, Leuwer R, Dubrowski A (2007): Using a virtual reality temporal bone simulator to assess otolaryngology trainees. Laryngoscope 117 (2), 258-263.