THE VALUE OF PSEUDO-3-DIMENSIONAL CT IMAGES IN NAVIGATED ENDOSCOPIC SINUS SURGERY

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The introduction of intraoperative navigational systems to head and neck surgery, particularly endoscopic sinus and frontobasal surgery, offers a new method of anatomical orientation and increases the safety of surgical procedures. However, this new instrument demands very advanced image data input, which can define delicate structures (e.g. the anterior ethmoid canal) and complicated relationships among them. The objective of our study is to determine the value of 3-dimensional CT images in navigated endoscopic sinus surgery. In our study, 3 cadaver heads and 3 patients with chronic sinusitis were scanned with 1mm axial slices on a Toshiba X-Vision spiral CT scanner, which is limited to the area of the ethmoid and the frontal skull base. Three-dimensional images were reconstructed on a workstation minicomputer (X-Tension) by using a special software package. The 3-dimensional CT images were observed in a sagittal-view, and the anterior ethmoid canal was observed and identified by an endoscopic sinus surgery (ESS) surgeon. Then the data was transmitted to the workstation computer of the navigation system (Evans III, optical system, Tomiki Medical Instrument Company, Ltd.). Finally, cadaver heads were dissected and ESS was performed on the patients, both with the assistance of the navigational system. The anterior ethmoid canals on both sides of all the cadavers and patients were successfully identified on the 3-dimensional CT images, but we failed to achieve 3-dimensional CT-image-guided intraoperative navigation, due to the inadequacy of the software on the navigational system we used. We found that: 1) The sagittal-view of 3-dimensional CT images helped surgeons to easily identify not only the anterior ethmoid canal itself, but also other important landmarks, and the complicated relationships among these structures can be easily understood. 2) The anterior ethmoid canal can be identified on sagittal-view of 2-dimensional CT images by experienced ESS surgeons, but it was not practical to use the 2-dimensional images to locate the anterior ethmoid canal intraoperatively, since it is rather time-consuming. 3) We conclude that the 3-dimensional CT-image-guided navigational system would be useful in ESS, since surgeons can more easily identify the anterior ethmoid canal and other important landmarks on sagittal-view of 3-dimensional images, enabling them to more confidently locate high-risk areas and avoid intraoperative complications.

Endoscopic sinus surgery (ESS) is one of the most commonly performed procedures in the specialty of otorhinolaryngology, and is associated with a definite risk of intraoperative complications. Intraoperative image guidance is expected to have a major positive effect on ESS by allowing surgeons to remove pathology more efficiently. It has the potential to improve the surgeon’s confidence and allow visualization of the patient anatomy, particularly during revision procedures and in cases with altered anatomy. As a
consequence, the incidence of complications associated with the procedure is expected to decrease, making it a safer procedure.

The roof of the anterior ethmoid is one of the most high-risk areas in ESS, in particular, the area around the anterior ethmoid canals (Figure 1). In this region, the lateral wall of the olfactory fossa is formed by the lateral lamella of the cribiform plate, which has a mean thickness of 0.2mm. At the ethmoid sulcus, the thickness of the wall may be reduced to 0.05mm, making the bone here only 1/10 as strong as that at the roof of the ethmoid. In some cases, the anterior ethmoid canal shows bony dehiscence that results in a partially or completely open canal. Hence, even slight force here could damage the lateral lamella of the cribiform plate and the anterior ethmoidal artery, leading to the development of intracranial complications, and severe bleeding. In order to avoid these complications, it is essential to identify the anterior ethmoid canals intraoperatively.

An intraoperative computer-assisted navigational system has been developed with the recent improvements in imaging techniques such as CT and MRI. But at present, the image data used for intraoperative navigation consist mostly of 2-dimensional images, that is, conventional axial and coronal slices. These conventional 2-dimensional CT images have some shortcomings: 1) The structures lying perpendicular to the sagittal plane can not be seen satisfactorily; 2) no stereo images are available for understanding the complicated relationships among the structures; 3) the slices are too thick to show some fine structures.

Our study was aimed at trying to demonstrate the anterior ethmoid canal in 3-dimensional CT images reconstructed from 2-dimensional CT slices, so as to enable the use of the image data in an intraoperative navigational system.

**Key words:** Computer tomography, Three dimensional imaging, Intraoperative navigation, Endoscopic sinus surgery.

**MATERIALS AND METHODS**

3 cadaver heads and 3 patients with chronic sinusitis were studied between July and September 1999.

All the cadaver heads and the patients were scanned in 1-mm axial slices on a TOSHIBA X-VISION spiral CT scanner, limited to the area of the ethmoid and frontal skull base, using 120kv and 200mA, with the images displayed in a 512×512 matrix. Three-dimensional images were reconstructed on a workstation minicomputer (X-TENSION) using a special software package. Sagittal-view 3-dimensional CT images were examined, and the anterior ethmoid canal was identified by an ESS surgeon. The window of observation on the 3-dimensional sagittal-view CT scans was between 100 to 2,000 HU, and could be altered to demonstrate the anterior ethmoid canal with ease.

The data were then transmitted to the workstation computer of the navigational system (Evans III, optical system, TOMIKI Medical Instrument Company Ltd.). Finally, the cadaver heads were dissected and ESS was performed on the patients, both with the assistance of the navigational system. On the cadaver heads, metal pins were inserted into the anterior ethmoid canals from the orbit prior to the dissection.

**RESULTS**

The anterior ethmoid canals of both sides were identified in all the cadavers and patients on the 3-dimensional CT images (Figure 2). They were usually found in the anterior part of the frontal skull base, between the posterior wall of the frontal sinus and the basal lamella of the middle turbinate, seen as a round or oval cross section of the tubular structure.

We attempted to input the data into the navigational system in order to achieve intraoperative 3-dimensional-image-guided navigation. However unfortunately, the navigational system we used was only able to reconstruct combined 2-dimensional CT images (we refer to these as “pseudo-3-dimensional CT images”) rather than true 3-dimensional CT images.
Figure 1. Anterior ethmoid canal (AEC) and its surrounding structures. The lateral wall of cribriform plate and anterior ethmoid canal are the most easily damaged structures in this area. AEC = anterior ethmoid canal, TAE = tegmen of anterior ethmoid, LLCP = lateral lamella of cribriform plate, OW = orbital wall, F = frontal sinus.

Figure 2. A sagittal cutview of 3-dimensional CT image limited to the ethmoid sinus and frontal skull base. AEC = anterior ethmoid canal, PWF = posterior wall of frontal sinus, BL = basal lamella of middle turbinate, AWS = anterior wall of sphenoid sinus.

Figure 3. A navigation view of cadaver dissection before the bony wall of AEC being removed. Yellow arrow: marked anterior canal on "psuedo-3-dimensional CT" image, Black arrow: tip of probe.

Figure 4. A navigation view of cadaver dissection after the bony wall of AEC being removed. Yellow arrow: the marked anterior canal on "psuedo-3-dimensional CT" image, Black arrow: the metal pin inserted into the anterior ethmoid canal.
images. We therefore attempted to recognize the anterior ethmoid canal in sagittal-view 2-dimensional CT images and marked it in red, so as to be able to easily locate this structure during dissection or operation.

Figures 3 and 4 show the images in the dissected cases. We can see that the crosshair on the navigational display is close to the part marked in red (Figure 3), and in the endoscopic view, the tip of the probe is pointing to the area just behind the posterior wall of the frontal sinus. After we removed the bony wall here, the metal pin was found, and repeated navigation showed that it matched the area marked in red (Figure 4).

On the other hand, during ESS also, the same results were obtained in all the 3 cases. Identification by the pseudo-3-dimensional-CT-guided navigation matched the anatomical landmarks; the anterior ethmoid canal itself can, however, never be exposed in a live human.

**DISCUSSION**

The anterior ethmoid is one of the most high-risk areas in endoscopic sinus surgery. But it is usually difficult to identify it intraoperatively due to its poor exposure and anatomical variations.\(^{15}\) Methods of identifying this structure have been described, however, all these methods require expert knowledge of the anatomy of the ethmoid and the frontal skull base and also long experience in endoscopic sinus surgery.\(^{2}\) Actually, the position of the anterior ethmoid canal has always been only supposed instead of confirmed intraoperatively. Thus, intraoperative image guidance is helpful in ESS. In order to enable the surgeons to recognize the important landmarks and vital structures more clearly, and for stereognosis, the image data of intraoperative navigational systems are extremely useful.\(^{9}\)

Conventional CT images are 2-mm to 5-mm, axial or coronal slices. The anterior ethmoid canal is about 2mm in diameter, and in slices too thick, it cannot be easily visualized. Thus, we attempted to obtain 1-mm axial slices to allow clear and detailed visualization.

Since the anterior ethmoid canal runs forward and medially from the orbit, a sagittal view might be the best to demonstrate it. But a sagittal-view 2-dimensional CT image is often confusing when ESS surgeons attempt to identify the canal from its surrounding ethmoid cells.

Hence, we employed the method detailed above, that is reconstruction of sagittal-view 3-dimensional CT images of the ethmoid and the frontal skull base in 1-mm axial slices. With these stereognostic images, the anterior ethmoid canal is seen clearly separated from the ethmoid cells around it, and the complicated relationship among the anatomical structures can be easily understood.

A navigational system is a high-tech surgical aid that makes use of recent advances in diagnostic imaging and computer technology. In such a system, the operation site is visualized by CT or MRI, so that the spatial relationship between the surgeon and the operation site can be grasped in real time. Application of the navigational system to otolaryngology head and neck surgery should permit safer operation, especially when attempting re-operation on anatomically ambiguous target organs, surgery on lesions extending to organs at high risk for complications, and minimally invasive surgery. We have introduced a navigational system for various types of surgery in otolaryngology since 1997 and have reported on the usefulness and problems of such navigational systems.\(^{6-8}\) In the present study, we failed to achieve a real 3-dimensional-image-guided intraoperative navigation, due to the lack of availability of suitable software on the navigational system. However, we found that for ESS, pseudo-3-dimensional images packaged to the system were more useful than 2-dimensional images, on which demonstration of the anterior ethmoid canal could take 1 to 2 hours. This situation is expected to improve soon with the development of new software. As reported by us before, the Evans has an average error of less than 2mm, and this error could occur while attempting to visualize the anterior ethmoid canal. However, this error is not due to the image data itself, but to the hardware of the navigational system and the method of registration. Further effort should therefore be made to develop superior navigational systems and new methods of registration, so that the accuracy of the navigational system...
is improved.

CONCLUSION

In our research, 3 cadaver heads and 3 patients with sinusitis were studied to evaluate the usefulness of 3-dimensional CT reconstruction in navigated endoscopic sinus surgery. We found that: 1) Sagittal-view of 3-dimensional CT images could help surgeons to easily identify not only the anterior ethmoid canal itself, but also other important landmarks like the posterior wall of the frontal sinus, basal lamella of the middle turbinate and anterior wall of the sphenoid sinus. Furthermore, the complicated relationships among these structures can also be easily understood. 2) The anterior ethmoid canal can be identified on sagittal-view 2-dimensional CT images by experienced ESS surgeons. But it is not practical to use 2-dimensional CT images intraoperatively to locate the anterior ethmoid canal, since it is rather time-consuming. 3) We propose that the 3-dimensional-CT-image-guided navigational system would be useful in ESS. Since surgeons can more easily identify the anterior ethmoid canal and other important landmarks on sagittal-view of 3-dimensional CT images, the surgeons can be more confident in locating the high-risk area and therefore avoid intraoperative complications.

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