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Original Article

Study of frontal recess anatomy based on three-dimension computed tomography images reconstruction in Chinese subjects without frontal sinus disease

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Abstract: Background: The complication of frontal recess brings many difficulties to the doctor's surgery operations, and comprehensive understanding of frontal recess anatomy is essential for the successful treatment of subjects with frontal sinus disease. The purpose of the study is to describe the feature of the 3D model of frontal recess, and obtain the true image of the important anatomical structures of the frontal recess region to conduct surgery. Methods: A retrospective study of thirty Chinese subjects (60 sides) without frontal disease underwent spiral computed tomography scans, and multiplanar reconstruction images were performed on a computer workstation. The structure and parameter of the frontal recess, the sgger nasi cell and adhere style of the uncinate process were recorded precisely. Results: After the reconstruction, a 3D model very close to the true state of the nasal cavity-sinuses cell was obtained, in which parts of the frontal recess can be clearly identified as agger nasi cell, frontal cell and other important structures. Conclusions: This study developed an advanced technique and measurement from 3D reconstructed images of the frontal sinus. The projects resulted in better preoperative subject counseling and in predicting postoperative improvement in clinical status.

Keywords: Frontal sinus, anatomy, computed tomography, three-dimension, frontal cell

Introduction

Frontal recess is the most complicated area in the nose and paranasal sinuses, and this space may be obstructed by over-pheumatized cells around the recess such as agger nasi cells (AN), type 1-4 frontoehmoid cells (Kuhn), and suprabullar cells (SBCs). The complexity of this area brings many difficulties to the doctor's surgery operations, and comprehensive understanding of frontal recess anatomy is essential for the successful treatment of subjects with frontal sinus disease. Endoscopic examination and instrumentation, as well as high-resolution computed tomography (CT) scans, have changed the perspective for surgical anatomy in this region. In particular, CT scans has been the gold standard in the pre-FESS evaluation. Frontal recess anatomy is critical for correctly evaluation and management of frontal sinus diseases, especially the accurately removing of the cells around the region in endoscopic surgery of frontal sinus. The purposes of the study were to describe the feature of the three-dimension computed tomography (3D CT) model of frontal recess region, and provide the critical clinical information to surgeon.

Materials and methods

The study was performed at the department of the otolaryngology and the Department of the Radiology, Longgang ENT hospital. From March to May 2013, 30 subjects (60 sides) were involved in the study. The subjects were 23

Table 1. Clinic features and characteristics of subjects involved in this study

Subjects' characteristics and clinic features		
Gender	Male: 23	Female: 7
Age	>17	<50
Diseases	No frontal sinusitis, no sinonsasl polyposis, no maxillpfacial trauma, no congenital anomaly, and no sinus surgery.	

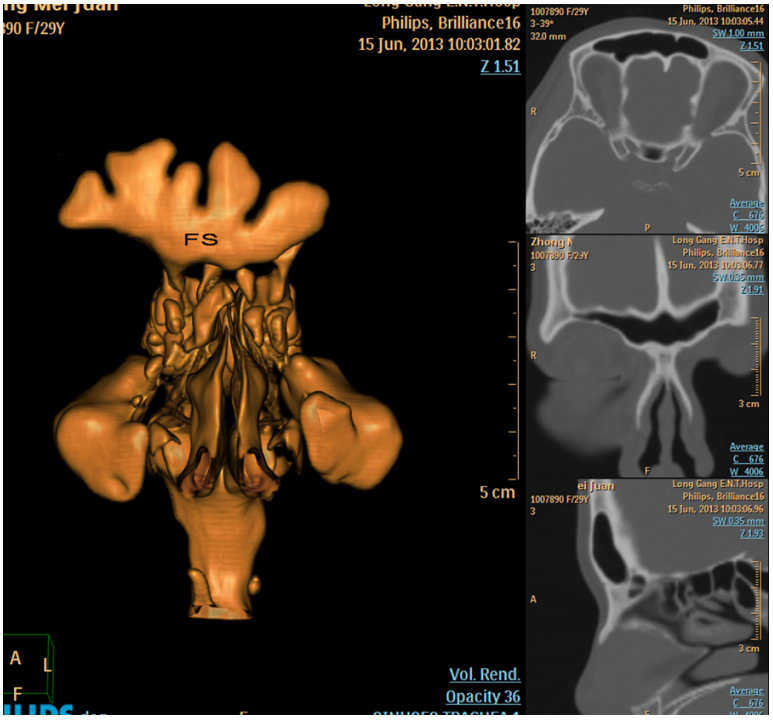

Figure 1. One-side frontal sinus (FS) over-developed, another side frontal sinus was absent.

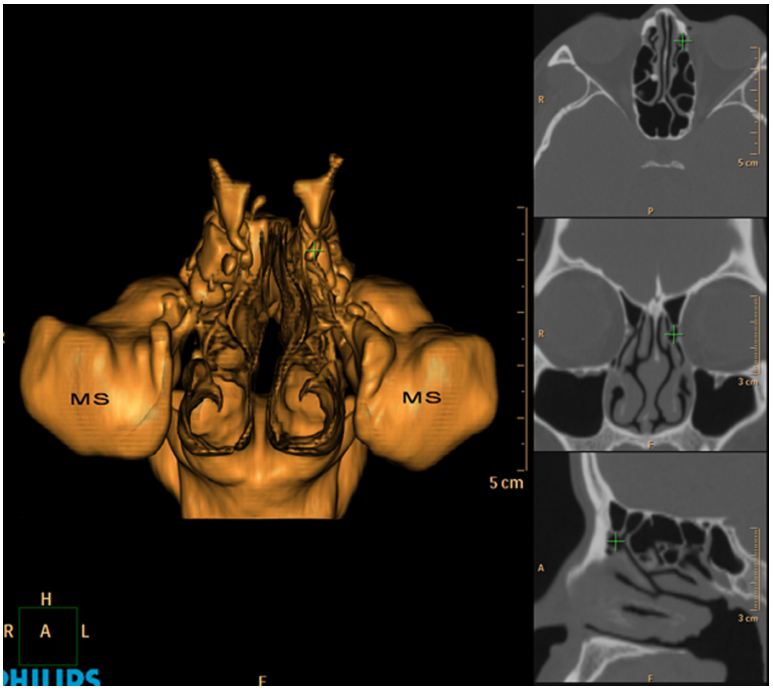

Figure 2. Both side frontal sinus was hypoplastic.

males and 7 females, aged between 17-50 years (**Table 1**). The exclusion criteria were: frontal sinusitis, sinonasal polyposis, age <17 years, maxillofacial trauma, congenital anomaly, and sinus surgery [1].

High-resolution spiral CT scanning of frontal was obtained with 1 mm section thickness (Philips Brilliance, Holland), bone windows. The field of view had a matrix size of 512×512 pixel. The following scanning parameters were used: kV=120, mA=250. Computer-aided CT review was performed at Philips Extended Brilliance Workspace 3.5. For the measurement of the frontal sinus and agger nasi, the SINUS Trachea analysis program was applied. First, the shape of the paranasal sinus filled with the air was reconstructed three-dimensionally. Then the location of the frontal cells was assessed while observing the coronal, axial, and sagittal images simultaneously. This study was approved by the ethics committee of the Longgang ENT hospital, Shenzhen, People's Republic of China. Written informed consent was obtained from all participants. Subjects' information was eliminated according to the requirement of the committee.

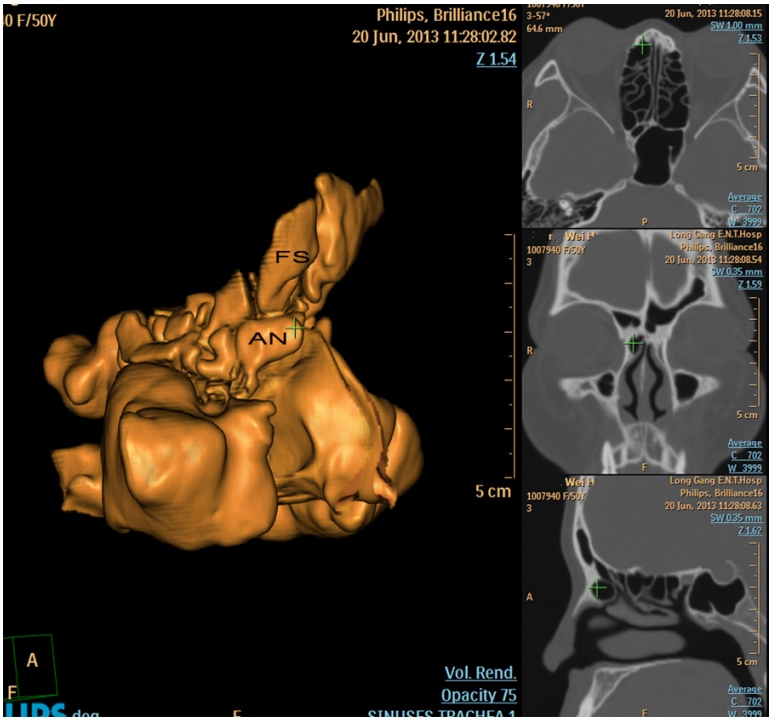

Figure 3. The shape of the nasi agger cell (AN) looked like the camel.

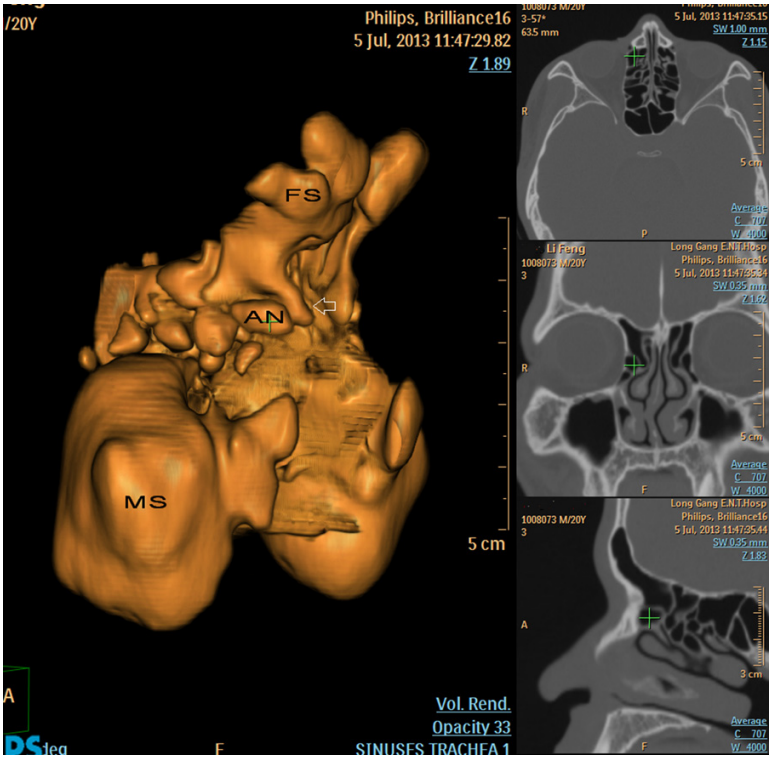

Figure 4. A recess (white arrow) exits between the unicate process and the aggge nasi cell (AN).

We observed the cells and other pheumatized structure in the frontal recess. Traditional three-dimension CT images were viewed in the coronal, sagittal, and axial planes in soft and bone windows before reconstruction. Before commencing the formal review of the CT scans, standardized criteria for frontal recess pneumatization patterns were developed as Kuhn and other researchers defined. While rotating the three-dimensional model up and down as well as right and left, excluding other sinuses structure out frontal recess distinguished with the tools in the software, only the frontal sinus was left in the measurement window, and the parameters were thus measured. The diameter of the right and left frontal sinus were measured separately, and similar to the measurement of the length and width of the agger nasi cells, the frontal beak was considered the inferior margin of the frontal sinus, and the area above it was considered to be the frontal sinus. The height was measured in the area where the length was longest on coronal images. The width was measured in the area where the width was widest on axial or coronal images. The 3D anteroposterior length of the agger nasi cell was measured in the area where the length was longest on the sagittal images.

Results

A total of 30 subjects s met the inclusion criteria, and 60 sides were reviewed. We invested the 3D anatomical feature of the frontal recess cells and drainage way of frontal sinus, already described in the literature in common population by means of traditional triplanar CT scans. We then reported some significant 3D images feature of main frontal

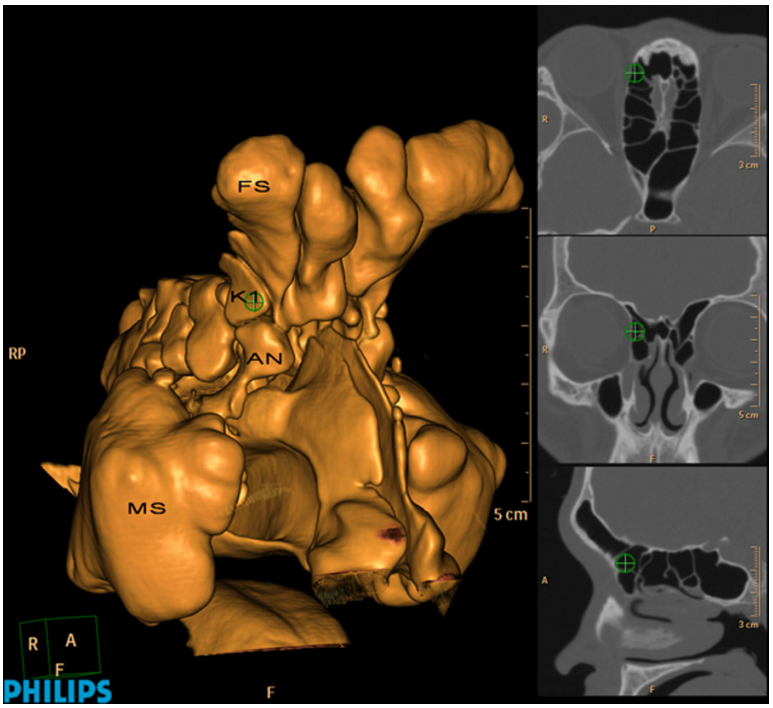

Figure 5. The Kuhn 1 cell (K1) was one cell located onto the aggge nasi cell (AN).

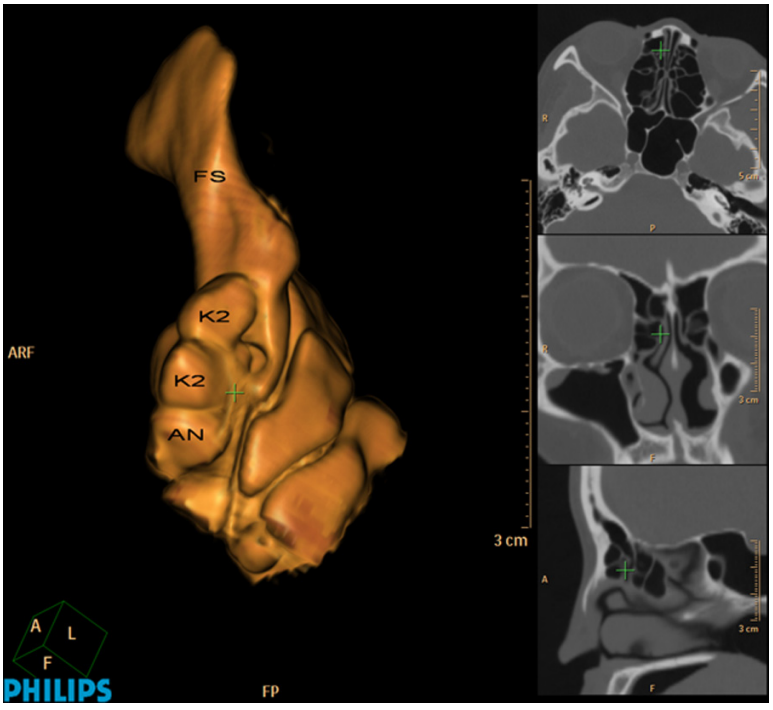

Figure 6. Kunh 2 cells (K2) were groups of cells existed on the agger nasi (AN) not extending into the frontal sinus.

recess cells and measure the height, width and depth of the agger nasi and frontal sinus.

Frontal sinus

In this report, we can observe the shape of the frontal sinus at any angle in the 3D-model. The frontal sinuses were not found in one subject (3.3%) of the 30 individuals. The frontal sinus was found on only one side (unilateral) in 1 subject (3.3%). In 5 sides, the frontal sinus was quite large, whereas the other side frontal sinus was correspondingly hypoplastic (**Figure 1**). In **Figure 1**, left side frontal sinus was absent, right side frontal sinus over-developed. Both side frontal sinus was hypoplastic in one subject (**Figure 2**).

The frontal sinus was divided into several types by the shape in the anterior view easily. The shape of the frontal sinus in anterior view can be classified as several groups: Triangle, Right-angled triangle, Quadrangle, Parallelogram Trapezoid, Fan-shaped, M-shaped, Crown, undefined shape, and so on.

Agger nasi

As we well know, the agger nasi cell is the most anterior and constant ethmoid cell, and swelling along lateral nasal wall anterior to the middle turbinate vertical attachment. Both coronal and axial CT images were critical for the assessment of the presence of the agger nasi cell. At least, the agger nasi cell was noted in 58 sides (93.3%), and agger nasi cell were not found in 2 sides (6.7%). But the two-dimension CT images provide us with limited information of the whole shape of the frontal cells. In the study, we find that the agger cells (**Figure 6**) were quite variable in size and shape by means

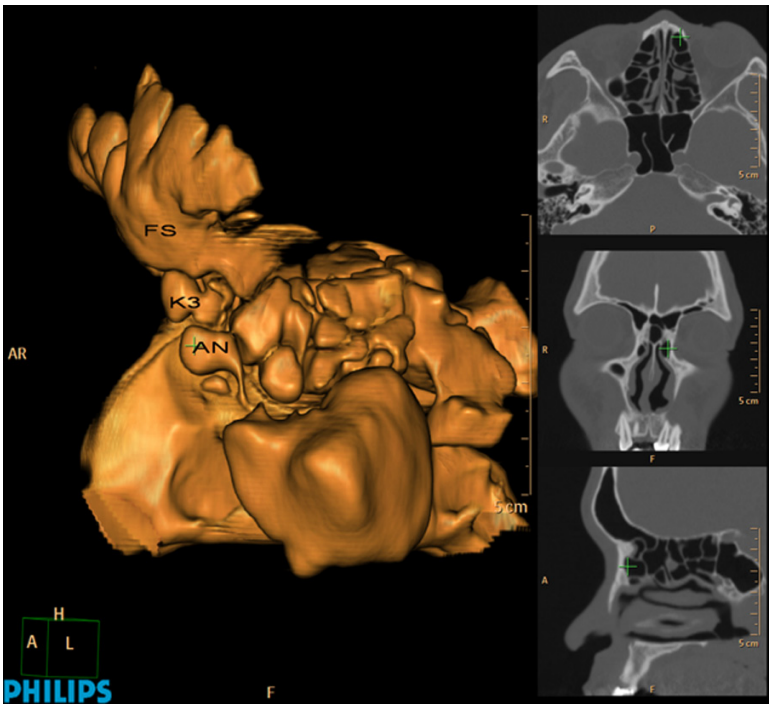

Figure 7. Kunh 3 cells (K3) were groups of cells located on the agger nasi (AN) not extending into the frontal sinus (FS).

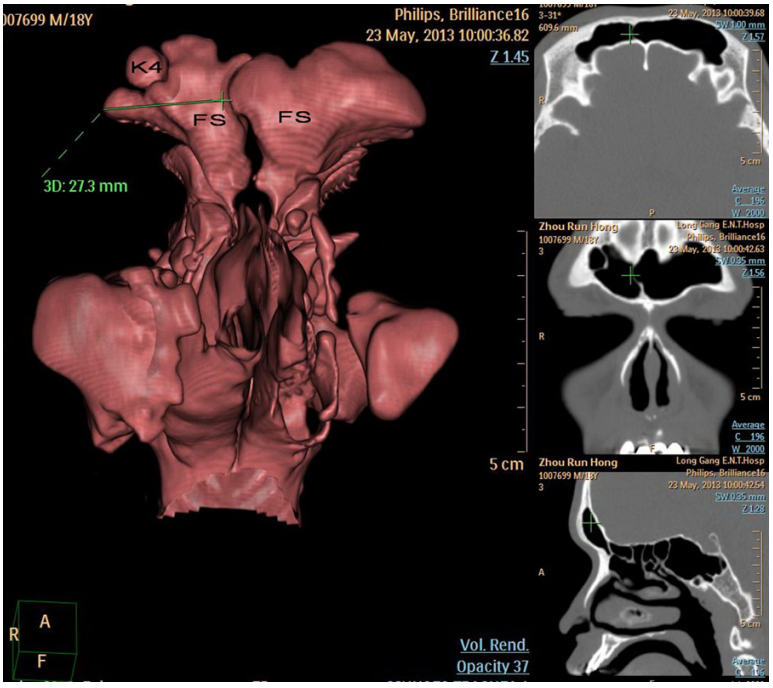

Figure 8. Kunh 4 (K4) cell was known as one isolated cell in the frontal sinus (FS).

of 3D-reconstruction. In some cases, the AN extended far over the frontal beak, whereas in other instances, the agger nasi cell was much smaller. In the situation of a large agger nasi cell, initial review of the 3D images suggested the presence of a large recess in frontal recess (**Figure 4**). The cross-sectional shape of the agger nasi cells at the baseline was classified by the shape of the AN in lateral view. There is also ample variation in the shape of the agger nasi (**Figures 3** and **4**).

Type 1-4 frontoethmoid cells (kuhn1-4)

As it was accepted, the frontoethmoid cells can be divided into four groups. Type 1 frontal cell known as Kuhn 1 cell is the simplest situation when only one cells within the frontal recess located above the agger nasi cell (**Figure 5**). Type 2 cells are groups of cells occurred onto the agger nasi cell (**Figure 6**). Type 3 is defined as one cell extended up into the frontal sinus (**Figure 7**). Type 4 frontal cell was an isolated cell in the frontal sinus (**Figure 8**).

The drainage way

There are two critical factors to influence the drainage way of frontal sinus, namely attachment of the uncinate process and the agger nasi cell. The interaction of the agger nasi cell and superior attachment of the uncinate determines the ventilation pathway of the frontal recess. In this study, we found that the situation of drainage pathway of frontal recess was more complicated than that we ever considered. In some cases, when the uncinate process attached to the lamina papyracea, the drainage way of frontal curved down between lamina and AN (**Figure 9**). When the

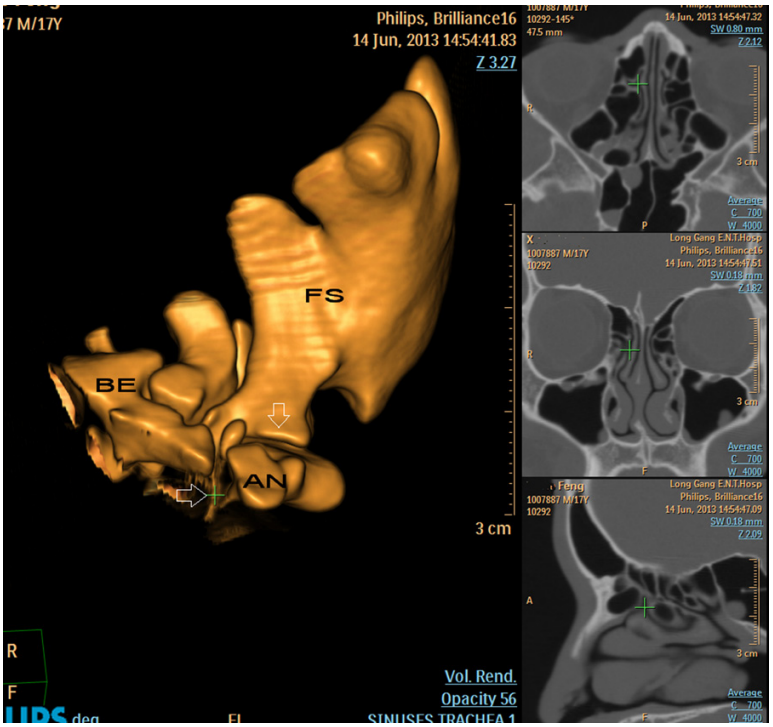

Figure 9. When the uncinate process attached to the lamina papyracea, the drainage way (white arrow) of frontal curved down between lamina and AN.

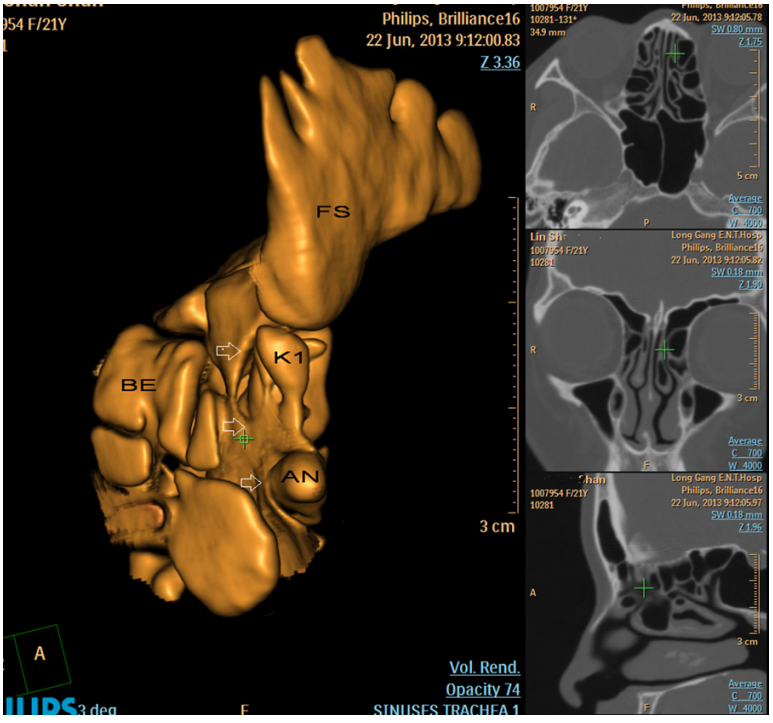

Figure 10. When the uncinate process attached to the lamina papyracea, the drainage way (white arrow) of frontal sinus (FS) curved down between lamina and Kuhn 1 cell (K1), AN.

uncinate process attached to the lamina papyracea, the drainage way (white arrow) of frontal sinus curved down between lamina and Kuhn 1 cell (K1), AN (**Figure 10**). When the uncinate process attached to skull base, the drainage way of frontal sinus passed after inside the AN. In some subjects, the superior unicate inserts onto skull base and extended upwards into the true frontal sinus (**Figure 11**). In this situation, the space of the frontal sinus was separated into two isolated parts by unicate process (**Figure 12**). When there were double attachment of uncinate process which inserted into the lamina papyracea and the anterior skull base, the drainage course of the frontal sinus were divided into two parts.

Discussion

The term "frontal recess" was first used to described the area of drainage way of the frontal sinus by van Alyea in 1941 [2]. There were the different types of ethmoidal cells pneumatizing in this area. This definition included the frontal cells (sometimes defined as the frontoethmoidal cells, as described by Kuhn et al. [3], the agger nasi cells, the supraorbital cells [4], and the interfrontal sinus septal cells [5]. Other cells which have also been described in this area include the suprabullar cells and the frontal bulla cells.

Until now, studies on the morphology or development of the frontal sinus primarily used the cadaveric skull bone, endoscopy, triplanar CT, magnetic resonance imaging, and so on. CT is a significant tool in clinical diagnosis and represents a significant advancement in radiology [6, 7]. CT is becoming increasingly available

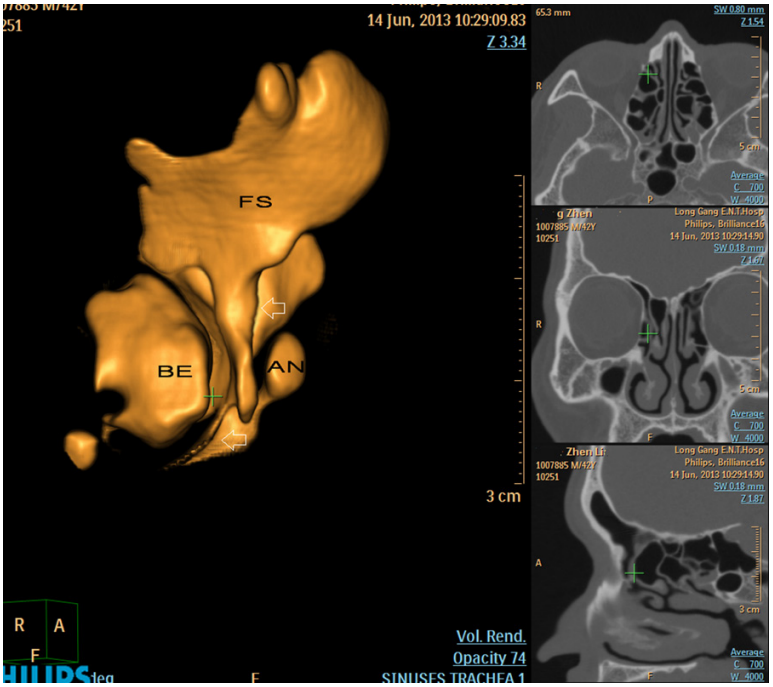

Figure 11. When the uncinate process attached to skull base, the drainage way (white arrow) of frontal sinus (FS) passed after inside the AN.

Figure 12. The superior unicate inserts onto skull base and extended upwards into the true frontal sinus (FS). In this situation, the space of the frontal sinus and the drainage way was separated into two isolated parts (white arrow).

and is gradually replacing conventional radiographs. It allows not only visualization of the internal structure of the sinuses in considerable detail but also pre-operation evaluation of their form with regard to size, shape, and bilateral distribution [8]. Many researchers have mentioned the usefulness of the frontal sinus in identification and pointed out the need for standardized measurements and techniques. Up to now, identification using the frontal sinus is usually available from a 2D image, even if it is a CT image. Previous researches of the frontal sinus using 2D images, radiography, and CT had some problems, such as the absence of standard procedure of reconstruction of the nose and parasinus, the need for many data to measure, and technical limitations [9]. Researchers have used different ways to assess the frontal sinus images. Furthermore, in order to generate the images of the 3D structure of the frontal sinus and the frontal recess, each cell around the area should be identified first on the coronal and parasagittal scan. After the confirmatory procedure of cellular location and size was finished, the building block of the frontal recess was created [10]. Then we developed the three-dimension picture of the anatomy of the frontal recess area, and the images were only a simple model that structure was confused. Now we created a really 3D model of the frontal recess and ostium with our reconstructive process directly. The 3D model could be rotated and cut additionally, and it reflected the true shape and arrangement of the frontal cells and other structure in frontal recess. We can explore inner space of the frontal recess,

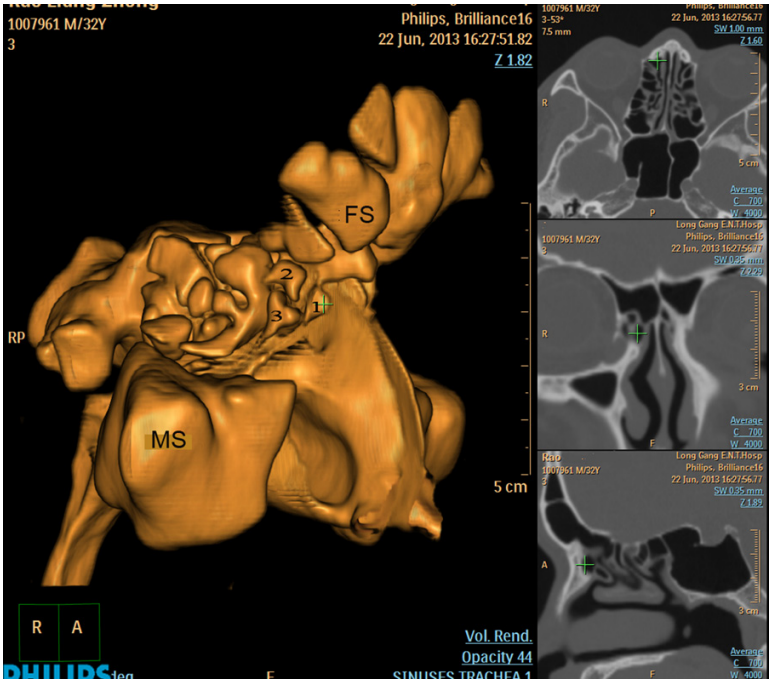

Figure 13. Some cells (cell 2, 3) located behind but not above the agger nasi cells (cell 1).

and identify every cells occurred in the area, too.

Surgeons who are starting their FESS careers still battle to conceptualize the possible configurations of the uncinate, agger nasi, and frontal ethmoid cells in the frontal recess.

Kuhn's universally accepted classification system classified them down into 4 types. Types 1-3 are all located above the agger nasi cells: A type 1 cell was defined as a single anterior ethmoid cell within the frontal recess above the agger cell [1]. Type 1 was found in up to 37% of frontal recesses [6]. Type 2 cells were termed as groups of frontal cells above the agger nasi cells. Type 2 cells were found in up to 19% of recesses [11]. Type 3 cells (6-8%) are a single cell located above the agger nasi but that extends superiorly from the recess, over the frontal beak, up to the frontal sinus [12]. Type 4 cells are isolated cells located within the frontal sinus. They are confined at an anterior level by the anterior frontal table. The posterior wall of these cells is the free partition in the frontal sinus. But the actual situation was likely more complicated than that we ever considered. In some rare cases, we found some cells located behind but not above the agger nasi cells. We could not define these cells as Kuhn cells, and termed them with posterior agger nasi cell (**Figure 13**).

The uncinate may insert into the lamina papyracea, skull base, middle turbinate, or combination of these struction [13, 14]. However, confusion still exists about how this upward continuation of the uncinate relates to the agger nasi cell [15, 16]. Our projects provide some useful information to understand these structures and their relation better. In the 3D CT images, we can find the drainage pathway of the frontal recess and its relation to the frontal cells easily.

This study illustrates the usefulness of the frontal sinus for individual identification, although some problems still exist, such as a fragmentary skull and the presence of CT images. This study confirmed nonmetric characteristics of the frontal cells and generated simple and accurate digital 3D CT images of the frontal recess [17]. We expect that this technique may be helpful in identifying and distinguishing the frontal cells and other structure within the frontal recess before the endoscopic frontal sinus surgery.

Conclusion

The anatomy and variations occurred within the frontal recess were always poorly described by lots of surgeons before endoscopic surgery previously. The traditional triplanar computed tomography scan can only provide 2D images. With these 3D-reconstruction methods of the fontal recess, we can explore the inner structure of the frontal cells and drainage way in the area better. On the whole, this study provided us a new insight to view the real structure of the frontal recess. The observed results allow us to describe the structure within the frontal recess more clearly. The researchers also easily understood the relationship of all kinds of frontal cells and ostium with the 3D-model of the frontal sinus.

Acknowledgements

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Disclosure of conflict of interest

None.

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