



Approach to frontal sinus via five frontal sinus drainage pathways

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Abstract

Purpose This study aimed to validate a method for successful frontal sinus surgery. The method classifies the frontal sinus drainage pathway (FSDP) into five categories based on three bony walls of the anterior ethmoid sinus, including the uncinate process (UP), accessory uncinate process (UPa), and basal lamella of the ethmoid bulla (BLEB), which was tested in actual surgical procedures.

Methods This study analyzed 53 sides of 48 patients who underwent frontal sinus surgery between October 2022 and March 2023. We classified the FSDPs using preoperative computed tomography (CT) and multiplanar reconstruction (MPR). During surgeries for FSDPs located anterior to the BLEB, we used a two-step method involving resection of the turbinal UP, followed by upward resection from the lower edge of the ethmoidal UP. For FSDPs located posterior to the BLEB, we resected the BLEB at the superior semilunar recess.

Results We confirmed the origin of each of the five types of FSDP during surgery. These origins, which were located at the lowest part of the anterior ethmoid, could be identified in the early stages of ethmoid sinus surgery before proceeding to the frontal recess area.

Conclusion The origins of the five types of FSDP, classified based on the bony walls, can be clearly and accurately identified during surgery. This provides a reliable method for preoperatively predicting and locating the inferior end of the FSDP (origin), without extensive manipulation of the cells formed in the frontal fossa.

Keywords Endoscopic sinus surgery · Frontal sinus · Frontal recess anatomy · Anterior ethmoid · Drainage pathways

Introduction

Frontal sinus surgery is considered to be one of the most challenging procedures in sinus surgery because of the complex anatomy of the frontal fossa [1]. Understanding the cells formed in the frontal fossa is important for successful frontal sinus surgery, and efforts have been made to identify, organize, and classify these cells [2, 3].

Several studies have described the types and locations of the frontal sinus drainage pathway (FSDP). For example, the

FSDP has been classified into several types depending on whether the superior end of the uncinate process (UP), the ethmoidal UP (coined by Zinreich et al. [4]), is connected to the lamina papyracea (LP), skull base, or middle turbinate (MT) [5, 6]. It has also been reported that the FSDP is formed between the UP and MT anterior to the basal lamella of the ethmoid bulla (BLEB) [1, 7] and between the anterior compartment (the agger complex) and the posterior compartment (the bullar complex) [8].

The frontal sinus is considered to develop from one of the ethmoid cells that grows into the frontal bone [9]; therefore, it is reasonable to assume that the variations in FSDP are similar to those in ethmoid cells. Classifying and organizing the drainage pathways of all the cells formed in the anterior ethmoid are necessary to understand the overall variations of the FSDP.

In a previous study, for this purpose, computed tomography (CT) and multiplanar reconstructions (MPR) were used to retrogradely trace all drainage pathways to the termination of the cell (anterior ethmoid or frontal bone) or

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the frontal sinus (frontal bone) [10]. The drainage pathways were classified into the following five types based on the combinations of bony walls: MT, basal lamella of the middle turbinate (BLMT), UP and accessory UP (UPa), BLEB, and LP.

The five drainage pathways were denoted as [UP-MT], [UP-LP], [UP-UPa], [UP-BLEB], and [BLRB-BLMT] (Fig. 1). For example, derived from [UP-MT], the frontal sinuses and cells formed at the terminus are denoted as [UP-MT-> FS] for the frontal sinus and [UP-MT-> C/Cs] for the cells. It was reported that among these five pathways, the four pathways of [UP-MT], [UP-LP], [UP-UPa], and [UP-BLEB] were formed anterior to the BLEB, and [BLEB-BLMT] was formed posterior to the BLEB [10].

The purpose of this study was to examine how the five classified origins of FSDP can be identified in actual surgeries and to evaluate whether the classification and identification of FSDP origins based on the bony walls are useful in frontal sinus surgery.

Materials

The subjects were 53 sides among 62 sides in 48 cases of frontal sinus surgery performed at [blinded for review] between October 2022 and March 2023, where the frontal sinus could be classified into five types using preoperative CT (MPR). All cases (1) had chronic sinusitis, including

the frontal sinus, on CT; (2) were resistant to conservative treatment; and (3) had no history of prior surgery. MPR was prepared using InVesalius[®]. The inclusion criteria were that it was possible to identify the UP (either a single UP or with an additional UPa) in the frontoethmoidal region and that it was possible to identify the connection point at the anterior end of the BLEB (either the frontal process of the maxilla [FPM] or the skull base). Sides that did not meet both criteria were excluded. Among the 53 sides, the number of sides classified by type were as follows: [UP-MT] 12 sides (22.6%), [UP-LP] 6 sides (11.3%), [UP-UPa] 9 sides (17.1%), [UP-BLEB] 23 sides (43.1%), and [BLEB-BLMT] 3 sides (5.7%) (Table).

The Ethics Committee of the clinic has confirmed that no ethical approval is required as this is an observational study. An informed consent was obtained from all participating patients.

Methods

The following methods were used to determine the location of the origin in each type of FSDP during surgery using a 30-degree endoscope, cutting forceps, microdebrider system, and a frontal seeker.

Four FSDPs formed anterior to the BLEB were examined in the following two-step operations: as the first step manipulation, the turbinal UP (coined by Zinreich et al. [4]) was removed to examine the cross-section of the lowermost

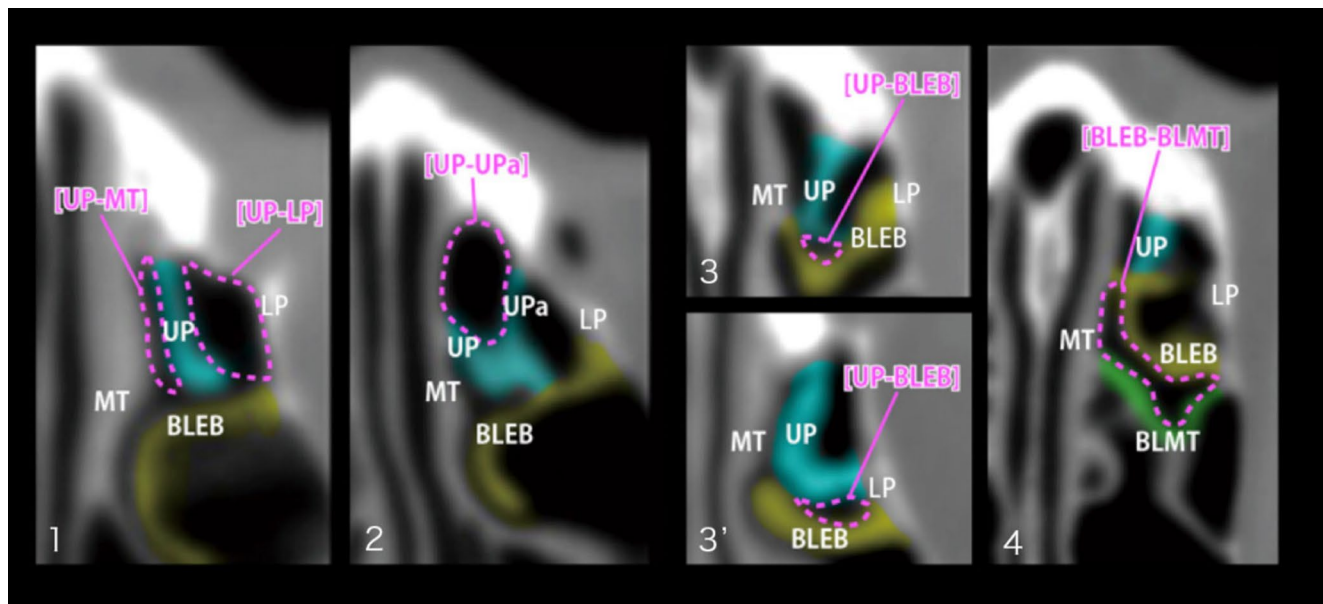


Fig. 1 Axial MPRs showing five FSDPs classified based on their bony walls. **(1)** [UP-MT] and [UP-LP] (dotted line) at the transition level from the turbinal UP to the ethmoidal UP. **(2)** [UP-UPa] formed between the UP and UPa. **(3 and 3')** [UP-BLEB] formed between the UP and BLEB. **(4)** [BLEB-BLMT] formed between the BLEB and BLMT. Note: [UP-MT], [UP-LP], [UP-UPa], and [UP-BLEB] are

formed anterior to BLEB, and [BLEB-BLMT] is formed posterior to BLEB. *UP/UPa* (blue)=uncinate process/accessory uncinate process; *BLEB* (yellow)=basal lamella of the ethmoidal bulla; *BLMT* (green)=basal lamella of the middle turbinate; *MT*=middle turbinate; *LP*=lamina papyracea

part of the ethmoidal UP and the gaps formed on both sides ([UP-MT] and [UP-LP]). In the second step manipulation, to examine [UP-UPa] and [UP-BLEB], the ethmoidal UP was gradually resected from the point where the posterior edge of the lowermost part of the ethmoidal UP connected to the BLEB, in an anterosuperior direction. Additionally, to examine [BLEB-BLMT], a pathway formed posterior to the BLEB was resected outward from the upper semilunar hiatus.

Results

The origin (starting point of the drainage pathway) of each of the five types of FSDP was confirmed as follows.

[UP-MT-> FS]

After the first step manipulation, the lower end of [UP-MT] was identified as the medial gap of the lowermost

part of the ethmoidal UP. [UP-MT] could be narrowed by [UP-LP-> C/Cs]; however, as a rule, it ascends along the posterior surface of the FPM to form the frontal sinus. Therefore, confirming this as an FSDP was not difficult (Fig. 2).

[UP-LP-> FS]

After the first step manipulation, the lower end of [UP-LP] was identified as the gap on the opposite side of [UP-MT], lateral to the lowermost part of the ethmoidal UP. Typically, [UP-LP] ascends to the frontal sinus along the lamina papyracea via a so-called agger nasi cell. Therefore, confirming this as an FSDP was not difficult (Fig. 3).

[UP-UPa-> FS]

The inferior end of [UP-UPa] is located above the inferior end of the ethmoidal UP. Therefore, [UP-UPa] was confirmed as a gap, lined by mucosa, between two bony

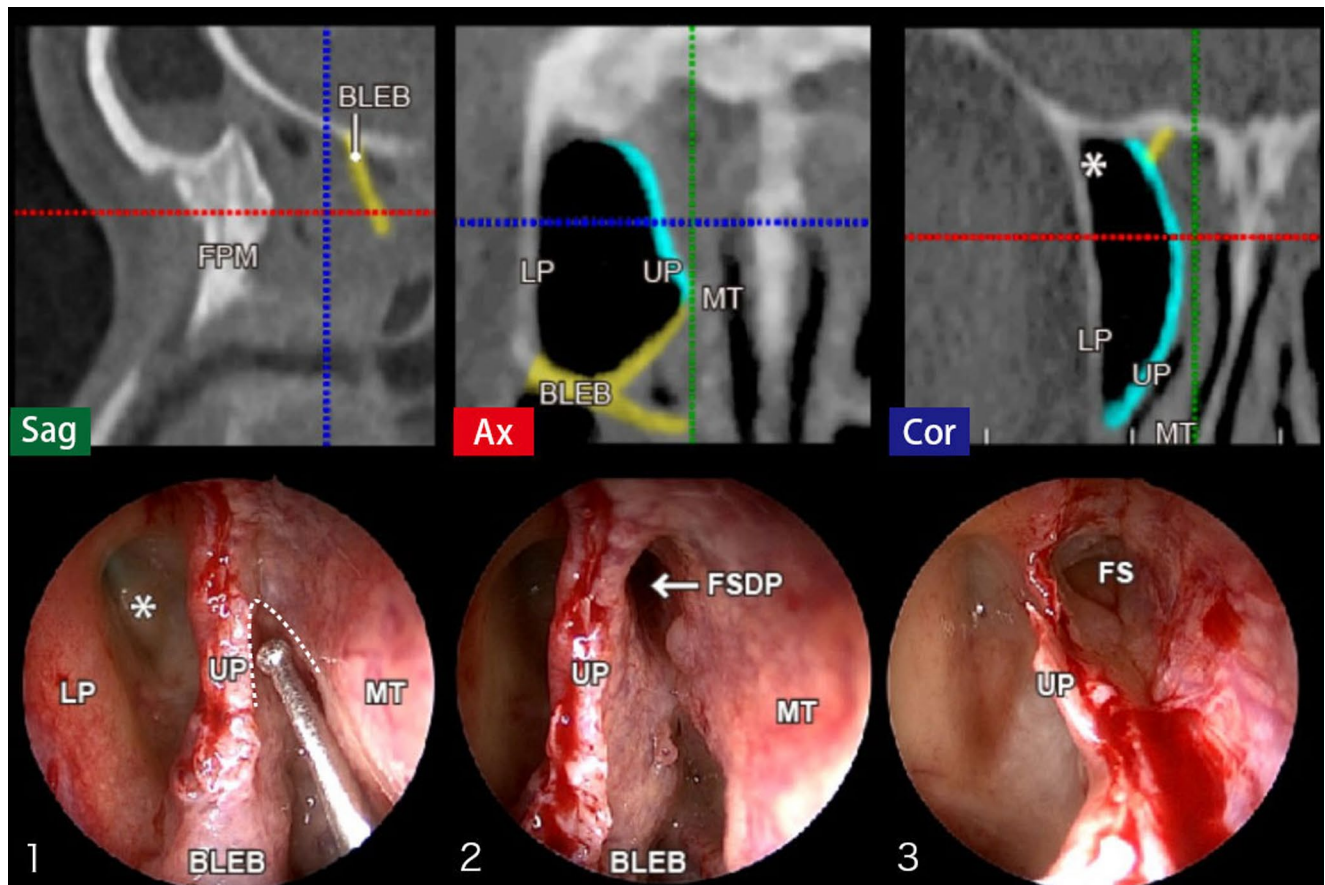


Fig. 2 Example of [UP-MT-> FS] (right side). MPR slices, **Sag** (sagittal), **Ax** (axial), and **Cor** (coronal), showing the position of [UP-MT] (cross hairs). Three thirty-degree endoscopic views showing surgical steps of frontal sinus surgery of [UP-MT-> FS]. **(1)** Turbinal UP has been resected, and cross-section of lowermost part of the ethmoidal UP is exposed. [UP-MT] (elliptical dotted line) is medial to the UP and,

in this case, [UP-LP-> C] (*) is formed lateral to the UP as a terminal cell. **(2)** [UP-MT] is traced superiorly. The FSDP is now identified medial to the UP. **(3)** The ostium of [UP-MT-> FS] is clearly identified. UP (blue)=uncinate process; BLEB (yellow)=basal lamella of the ethmoidal bulla; MT=middle turbinate; LP=lamina papyracea; FSDP=frontal sinus drainage pathway; FS=frontal sinus

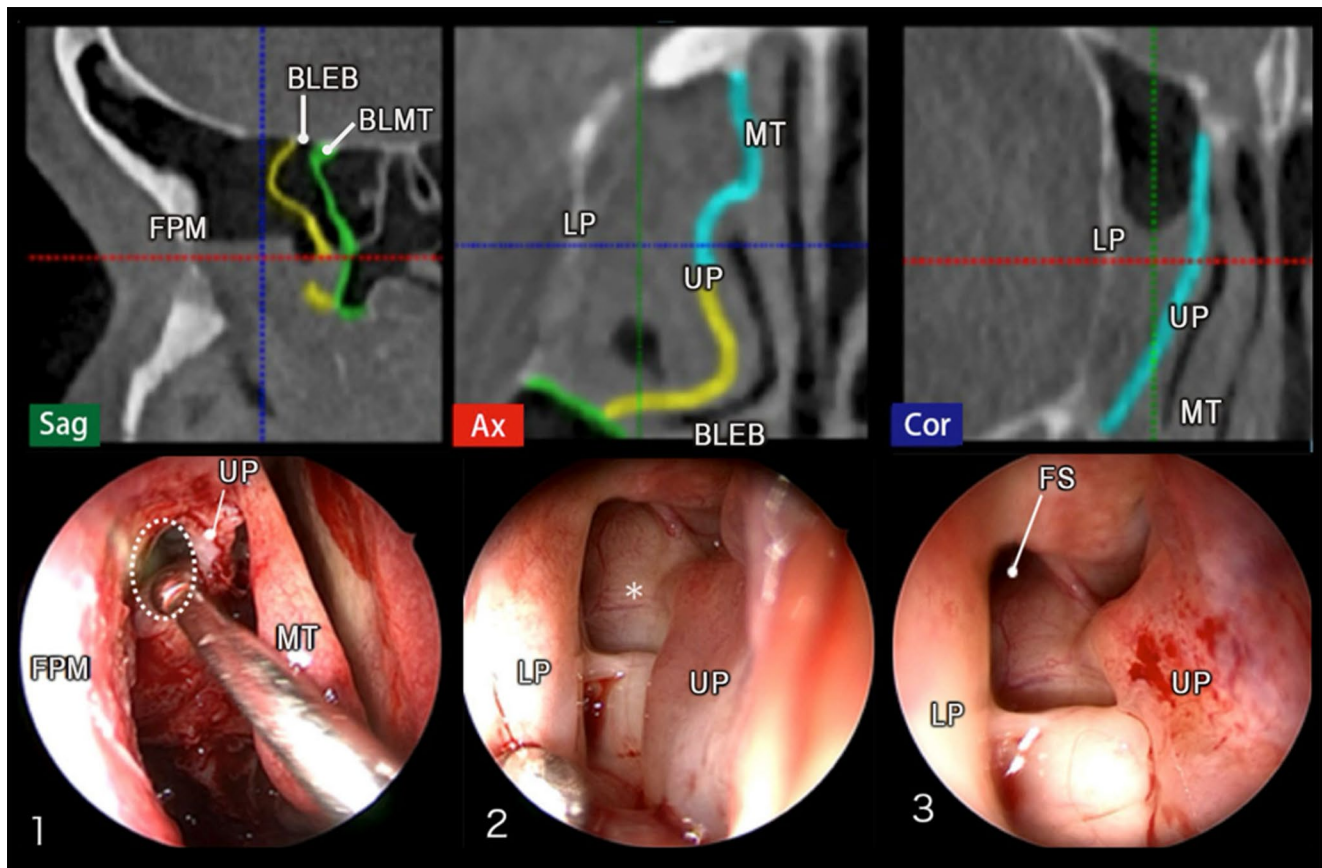


Fig. 3 Example of [UP-LP-> FS] (right side). MPR slices, **Sag** (sagittal), **Ax** (axial), and **Cor** (coronal), showing the position of [UP-LP] (cross hairs). Three thirty-degree endoscopic views showing surgical steps of frontal sinus surgery of [UP-LP-> FS]. **(1)** Turbinal UP has been resected, and cross-section of lowermost part of ethmoidal UP is exposed. [UP-MT] (elliptical dotted line) is lateral to the ethmoidal

plates after excising the lowermost part of the ethmoidal UP in the anterosuperior direction from the junction of the ethmoidal UP and BLEB. From here, [UP-UPa] extended upward to form the frontal sinus within the frontal bone (Fig. 4).

[UP-BLEB-> FS]

[UP-BLEB] exists in two types, depending on whether the posterior border of the ethmoidal UP is connected to the BLEB or the LP (3 and 3' in Fig. 1). The latter is rare and was confirmed after the first step manipulation as a gap between the ethmoidal UP and BLEB, both linked to the LP (3' in Fig. 1). However, in the majority of cases, the posterior end of the ethmoidal UP is connected to the BLEB. Therefore, in most instances, a gap lined by mucosa was observed between the posterior end of the ethmoidal UP and BLEB when the posterior edge of the inferior-most part of the ethmoidal UP was resected upward along the anterior surface of the BLEB. This

UP. **(2)** [UP-LP] is traced superiorly, and a wide gap leading to the frontal sinus is identified within the frontal fossa (*). **(3)** Looking towards the upper part of this gap, the opening of the frontal sinus can be identified. UP (blue)=uncinate process; BLEB (yellow)=basal lamella of the ethmoidal bulla; MT=middle turbinate; LP=lamina papyracea; FS=frontal sinus

was the inferior-most end of [UP-BLEB]. [UP-BLEB] typically presents as a narrow tube-like structure running along the surface of the medial wall of [UP-LP-> C/Cs] (Fig. 5).

[BLEB-BLMT-> FS]

[BLEB-BLMT] is an FSDP formed on the posterior side of the BLEB. It begins at the superior semilunar hiatus (SSH) and presents as a structure that simply expands from the SSH to the frontal sinus. Therefore, a direct approach to the SSH makes it easy to confirm and open the drainage pathway (Fig. 6).

Discussion

To date, frontal sinus surgery has been reported using two methods where one involves identifying the frontal sinus ostium after clearing the frontal recess cells [2, 11], and the

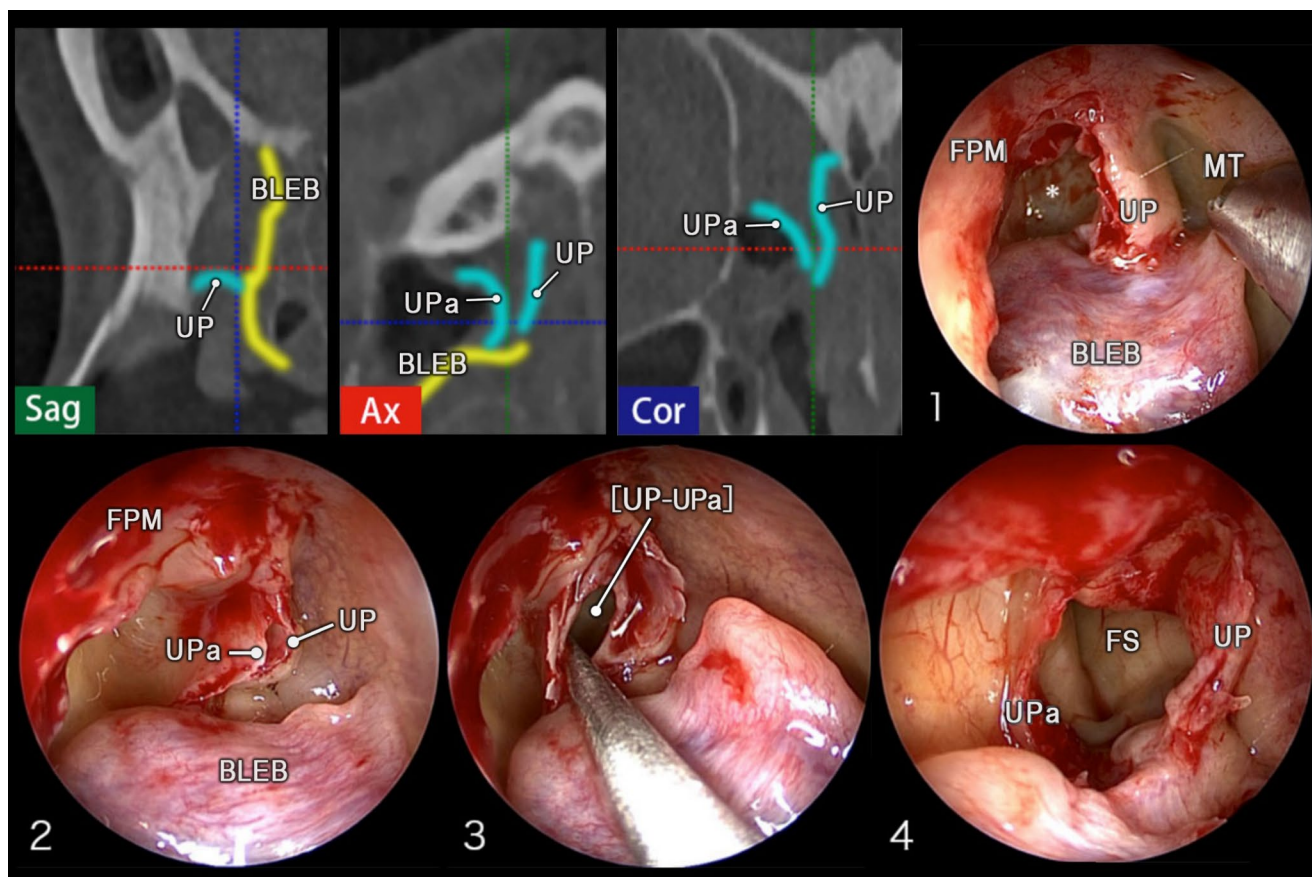


Fig. 4 Example of [UP-UPa-> FS] (right side). MPR slices, **Sag** (sagittal), **Ax** (axial), and **Cor** (coronal), showing the position of [UP-LP] (cross hairs). Four thirty-degree endoscopic views showing surgical steps of frontal sinus surgery of [UP-UPa-> FS]. **(1)** Turbinial UP has been resected, and a cross-section of the lowermost part of the ethmoidal UP is exposed. The UP divides the anterior space of the BLEB into two, with the lateral side of the UP being closed (terminal cell), and its roof is visible (*). **(2)** The posterior end of the ethmoidal UP,

which is connected to the BLEB, has been resected upwards along the anterior surface of the BLEB. The ethmoidal UP can be seen splitting into two lamellae at its posterior edge. **(3)** When observing between the two lamellae from below, the gap leading to the frontal sinus, referred to in this case as [UP-UPa], can be seen. **(4)** The frontal sinus continues above [UP-UPa] and is widely open. UP/UPa (blue)=uncinate process and accessory uncinate process; BLEB (yellow)=basal lamella of the ethmoidal bulla; MT=middle turbinate; FS=frontal sinus

other involves identifying the FSDP within the frontoethmoidal region [1, 5, 7, 8].

However, if the type of FSDP can be classified preoperatively based on the bony wall, it would be possible to predict the position of the inferior end (origin) of the FSDP. We confirmed that the preoperative prediction of the position of the inferior end of the FSDP almost exactly matches the position confirmed during surgery. In other words, if the type of FSDP can be classified preoperatively, its origin can be accurately predicted before surgery. At the same time, it becomes possible to identify the predicted origin of FSDP in the early stages of the surgery. Therefore, the traditional classification or the extensive clearance of the cells in the frontal recess, which has been used to locate the ostium of the frontal sinus, theoretically becomes unnecessary. If the origin of the FSDP is identified in the early stages of the surgery, it

provides a clear route leading to the frontal sinus before manipulating the frontal recess region.

In cases where advanced lesions are present, the lesions can obscure the outline of the bony wall as displayed on preoperative MPR. Therefore, preoperative classification based on the bony wall may become difficult. In particular, interpretation tends to be challenging in cases where the FSDP is formed between two thin bony walls, such as [UP-UPa] and [UP-BLEB]. Nonetheless, even in such cases, finding these FSDPs during the actual surgery is not particularly difficult. This is because, after the first step manipulation, if the inferior edge of the ethmoidal UP can be identified, the origin of these FSDPs will be either within the ethmoidal UP (between UP and UPa) or between the posterior edge of the ethmoidal UP and the BLEB. In other words, if the inferior edge of the ethmoidal UP is identified, using it as a guide and excising it from the inferior edge in an anterosuperior direction on

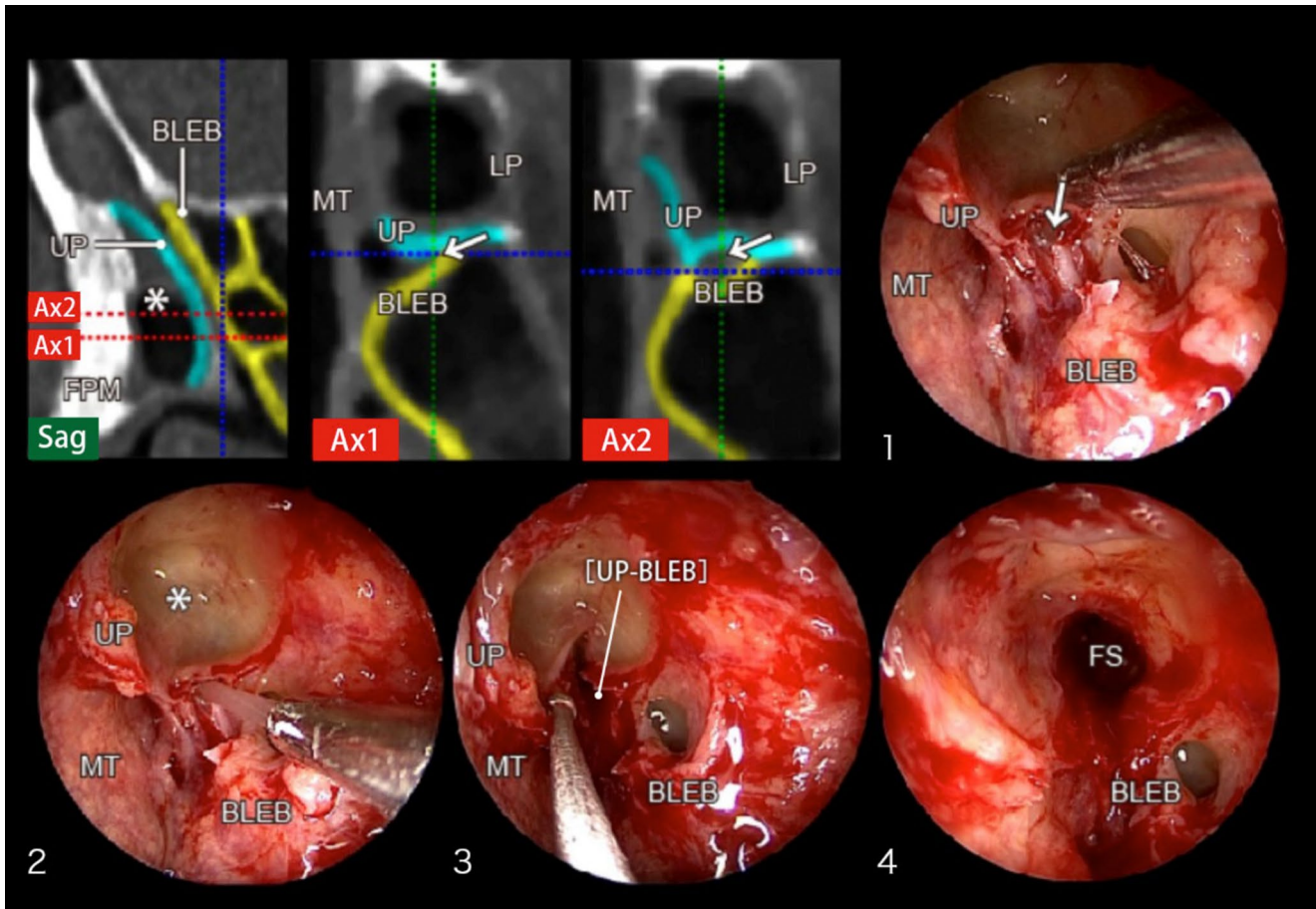


Fig. 5 Example of [UP-BLEB-> FS] (left side). MPR slices, **Sag** (sagittal), **Ax** (axial) 1, and **Ax2**, showing the position of [UP-BLEB] (cross hairs). In **Ax2**, [UP-BLEB] forms a tube-like structure. Four thirty-degree endoscopic views showing surgical steps of frontal sinus surgery of [UP-BLEB-> FS]. **(1)** The turbinal UP has been resected, and posterior edge of the inferior-most part of the ethmoidal UP is slightly resected at the anterior surface of the BLEB. A tube-shaped space surrounded by the UP and BLEB, as shown in **Ax2**, is visible

(arrow). **(2)** When a suction tube is applied to this space, it can be seen that accumulated secretion is drawn into the suction tube. [UP-BLEB] appears to run above the roof of [UP-LP-> C] (*). **(3)** [UP-BLEB] runs forward above the roof of [UP-LP-> C]. **(4)** The frontal sinus is opened by resecting the roof of [UP-LP-> C]. UP (blue)=uncinate process; BLEB (yellow)=basal lamella of the ethmoidal bulla; LP=lamina papyracea; FS=frontal sinus

the anterior surface of the BLEB will definitely lead to finding the origin of the FSDP.

Thus, conceptually, our surgery that uses the bony wall itself as a guide and excises the bony wall up to the frontal sinus can be considered a method that is significantly different from traditional surgeries, which use gaps as guides to open the frontal sinus.

Despite the progress in navigation systems, they do not supplant the need for the surgeon's anatomical understanding and judicious choice of approach, which remain crucial. In this regard, the most effective strategy involves identifying the expected FSDP type from preoperative CT scans and using intraoperative bony landmarks to navigate to the frontal sinus.

Conclusion

Preoperative classification of FSDPs based on bony walls using MPR completely matched FSDPs identified during surgery. Therefore, preoperative classification based on the bony wall enables for accurate prediction of the origin of FSDPs.

This classification method based on the bony wall is extremely useful in frontal sinus surgery for several reasons: (1) accurate prediction of the origin of FSDPs (one of five possible origins) before surgery, (2) easy identification of the origin of the FSDP early in the surgery, and (3) easy access to the frontal sinus opening by simply following the bony wall. This method is applicable even in cases with advanced lesions, as long as the bony wall is not absorbed.

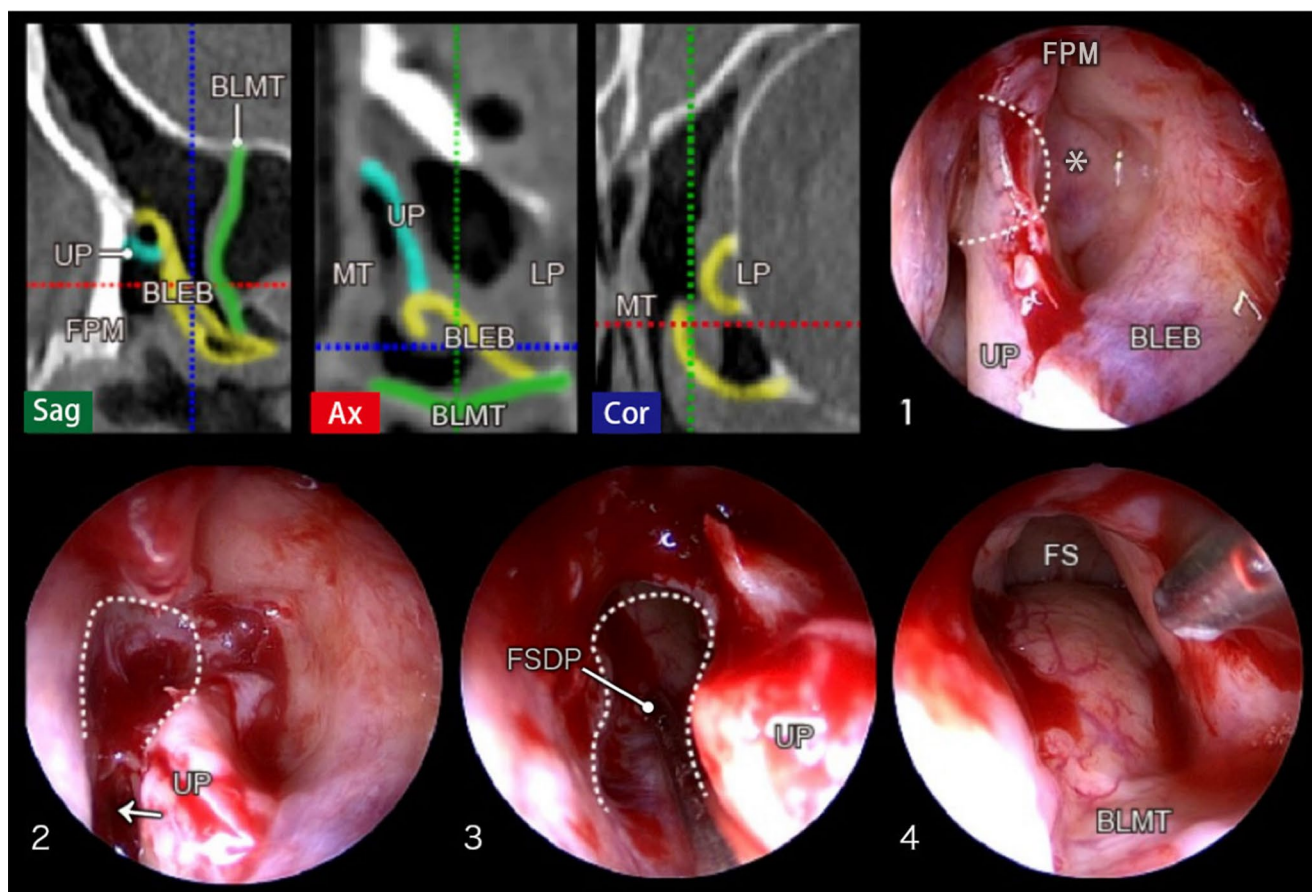


Fig. 6 Example of [BLEB-BLMT-> FS] (left side). MPR slices, **Sag** (sagittal), **Ax** (axial), and **Cor** (coronal), showing the position of [UP-LP] (cross hairs). Four thirty-degree endoscopic views showing surgical steps of frontal sinus surgery of [UP-BLEB-> FS]. **(1)** Turbinal UP has been resected. In this example, the roof of [UP-LP-> C] (*) is the BLEB connected to the FPM. Dashed line indicates the extent of ethmoidal UP to be resected to expose the BLEB forming the base of the FSDP. **(2)** Dashed line indicates the extent of BLEB to be

resected to access the FSDP. **(3)** Opened FSDP (dashed line). **(4)** Looking upward from the FSDP, it is continuous with the frontal sinus. UP (blue)=uncinate process; BLEB (yellow)=basal lamella of the ethmoidal bulla; BLMT (green)=basal lamella of the middle turbinate; LP=lamina papyracea; MT=middle turbinate; FPM=frontal process of the maxilla; FSDP=frontal sinus drainage pathway; FS=frontal sinus

This approach significantly simplifies and reduces the difficulty of frontal sinus surgery, which has traditionally been considered challenging due to the complex anatomy of the frontal fossa, and is key to achieving successful frontal sinus surgery.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Toru Kikawada. The first draft was written by Toru Kikawada and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The data are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate This is an observational study. The Ethics Committee of Nose Clinic Tokyo has confirmed that no ethical approval is required. Informed consent was obtained from all participating patients.

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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