Analysis of the Frontal Sinus Drainage Pathways Classifications in Computed Tomography by Radiological Image Viewer

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Abstract: **Background:** Over the last decade there has been increasing interest in the anatomy and surgical approaches to the frontal sinus. The frontal sinus is often cited as the most challenging area to approach in endoscopic sinus surgery (ESS). **Aim:** analysis of the frontal sinus drainage pathways classifications in computed tomography by radiological image viewer. **Methods**: A total of 200 cases met the inclusion criteria; 400 frontal recesses were reviewed. Gender distribution was 84 men and 116 women. The mean age was 43 years (range, 16-69 years). Indications for obtaining the CT scan are outlined in Table. None of the patients had clinical history or radiographic evidence of frontal sinus disease. **Results:** This study shows that the interrater agreement of ABC is higher than with the MBKC for both the air spaces anterior and posterior to the FSDP. **Conclusion:** The frontal sinus drainage pathways and the surrounding anterior ethmoid sinus represent one of the most complex anatomic regions of the skull base. An intimate knowledge of its anatomy and a clear understanding of its physiology and anatomic variants are required for safe and effective surgical management of frontal sinus drainage pathway problems.

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1. Introduction

As with any surgical procedure, a thorough knowledge of anatomy is the one most important factors in minimizing complications and maximizing one's chances of a good surgical outcome **(Perkins et al., 2010)**.

This is particularly important for otolaryngologists performing endoscopic sinus surgery, as each and every one of the paranasal sinuses are in close proximity to critical orbital and skull base structures **(Yoon et al., 2009)**.

A good knowledge of anatomy will enable the surgeon to operate with more confidence, by improving one's ability to correctly interpret normal variants from abnormal or pathological conditions, and determine an appropriate surgical treatment plan to reestablish mucociliary flow to the sinus **(Sharma et al., 2017)**.

This is even more critical for distorted anatomy, due to previous surgery or neoplasms. Furthermore, CT imaging has become an integral part of the diagnostic armamentarium for sinus surgeons **(Costa et al., 2009)**.

Technological advancements such as intraoperative navigational devices depend on the surgeon's proper identification of normal or abnormal structures on CT or MRI scans. However, despite this technology's intent of reducing complications, failure to know the sinus anatomy or properly identify critical structures on the scan may still result in disastrous consequences **(Zielinski and Nowinski, 2014).**

The frontal sinus hides in the anterior cranial vault surrounded by two thick layers of cortical bone. Its naturally draining "ostium", or frontal infundibulum, remains immersed in an intricate complex area covered by ethmoid cells and other anatomical structures that may not be so easy to find. In order to better understand frontal sinus anatomy, one must begin with its embryological development **(Al-Bar et al., 2016)**.

2. Patients and methods

A total of 200 cases met the inclusion criteria; 400 frontal recesses were reviewed. Gender distribution was 84 men and 116 women. The mean age was 43 years (range, 16-69 years). Indications for obtaining the CT scan are outlined in Table. None of the patients had clinical history or radiographic evidence of frontal sinus disease.

The cases underwent cone beam computed tomography (CBCT) from the highest portion of the frontal sinuses to the body of the mandible in a craniocaudal axis, and from the tip of the nose to the posterior cranial fossa in an anteroposterior axis.

Computed tomography (CT) scans of nose and paranasal sinuses will be utilized and using software image to evaluate different published Classifications.

They filled the anatomical report examining the CT scan. Interrater agreement regarding each variable of the classification systems will be estimated.

Expert head and neck radiologist studied the CBCT scan and completed an anatomical report (Ra) in consensus by applying the MBKC and ABC classification systems.

Statistical analysis

For each anatomical variant of MBKC (ANC, Kuhn's type, SBC, SOEC, FB, IFSSC, and CB) and ABC (A complex, B complex, type f, F, and R air space, and medial or lateral FSDP) the interrater agreement between radiologists, expert surgeon, and novice surgeon was estimated with Cohen's kappa. Both the simple (κ) and the linear weighted (lw-κ) Cohen's kappa were calculated for each variable.

The simple Cohen's kappa was adopted to compare dichotomic (ie, presence or absence of the FB) and non-dichotomic cardinal variables (ie, the type of Kuhn's cell) with each other and with non-dichotomic ordinal variables.

The linear weighted Cohen's kappa was adopted to compare non dichotomic ordinal variables (ie, the number of air spaces constituting the A complex).

A 95% confidence interval was calculated for each kappa value.

The values of Cohen's kappa were classified as follows:

$\kappa = 0$: no interrater agreement;

$0.0 < \kappa < 0.4$: poor interrater agreement;

$0.4 \leq \kappa < 0.6$: moderate interrater agreement;

$0.6 \leq \kappa < 0.8$: good interrater agreement;

$0.8 \leq \kappa \leq 1.0$: optimal interrater agreement.

Comparison between MBKC and ABC

The MBKC and ABC were compared according to the interrater agreement between different reporters (Ra vs S1, and S2 vs S1) in the anatomical description of a specific subunit of the frontoethmoidal region. For this purpose, the following categories, belonging respectively to ABC and MBKC, were matched:

A complex was compared with ANC and Kuhn's cell (s), representing the anatomical description of the spaces anterior to the FSDP.

B complex and type R air space were compared with SBC and FB, representing the anatomical description of the spaces between the FSDP and the basal lamella of the middle turbinate.

Type f and F air spaces were compared with the type of Kuhn's cell and FB, representing the anatomical description of the spaces protruding into the frontal sinus.

3. Results:

The classification of the FSDP in relation to the upper insertion of the UP showed optimal interrater agreement values (Ra vs S1: κ = 1; S2 vs S1: κ = 1)

The interrater agreement of the ABC was higher than that using the MBKC for all anatomical subunits of the frontoethmoidal area, except for ANC and FB. Both simple Cohen's kappa and linear weighted Cohen's kappa values are reported in Table 2 for the MBKC and in Table 3 for the ABC. Regarding the spaces between the frontal process of the maxillary bone and the FSDP, the ANC showed optimal interrater agreement (Ra vs S1: κ = 1; S2 vs S1: κ = 1), whereas the Kuhn's type of frontoethmoidal cell did not (Ra vs S1: κ = 0.52; S2 vs S1: κ = 0.62).

The A complex showed higher Cohen's kappa values (Ra vs S1: κ = 0.84; S2 vs S1: κ = 0.96) with nonoverlapping confidence intervals compared with the respective Kuhn's type values.

Considering the spaces between the FSDP and the basal lamella of the middle turbinate, only the SBC showed poor interrater agreement values (Ra vs S1: κ = 0.32; S2 vs S1: κ = 0.57), which were significantly lower compared to those of the B complex (Ra vs S1: κ = 0.73; S2 vs S1: κ = 0.86).

In addition, both FB (Ra vs S1: κ = 0.94; S2 vs S1: κ = 1) and type R (Ra vs S1: κ = 1; S2 vs S1: κ = 1) air spaces showed optimal interrater agreement.

For the spaces protruding into the frontal sinus, the ABC showed higher interrater agreement values (type f: Ra vs S1: κ = 0.81; S2 vs S1: κ = 0.87. Type F: Ra vs S1: κ = 1; S2 vs S1: κ = 1) (Table. 3) than MBKC only for Kuhn's type (Ra vs S1: κ = 0.52; S2 vs S1: κ = 0.62), whereas the FB showed high Cohen's kappa values (Ra vs S1: κ = 0.94; S2 vs S1: κ =1).

Furthermore, the SOEC (Ra vs S1: κ = 0.92; S2 vs S1: κ = 0.92), IFSSC (Ra vs S1: κ = 0.93; S2 vs S1: κ = 1), and CB (Ra vs S1: κ = 0.96; S2 vs S1: κ = 1) showed optimalinterrater agreement values.

Table 1: Cohen's kappa (κ) and linear weighted Cohen's kappa (Lw-κ) values of the anatomical variants of the modified Bent and Kuhn classification for radiologist-vs-expert surgeon matching (Ra vs S1) and in the beginner-vs-expert surgeons matching (S2 vs S1)

	Ra vs S1						
	ANC	**Kuhn**	**SBC**	**SOEC**	**FB**	**IFSSC**	**CB**
***K* (95% cl)**	**1 (na)**	**0.52 (0.38-0.68)**	**0.32 (0.06-0.59)**	**0.92 (0.84-1.00)**	**0.94 (0.82-1.00)**	**0.93 (0.68-1.00)**	**0.96 (0.83-1.00)**
***Lw-k* (95% cl)**	**1 (na)**	**0.66 (0.55-0.77)**	**0.32 (0.11-0.57)**	**0.92 (0.84-1.00)**	**0.94 (0.82-1.00)**	**0.93 (0.69-1.00)**	**0.96 (0.83-1.00)**

	S2 vs S1						
	ANC	**Kuhn**	**SBC**	**SOEC**	**FB**	**IFSSC**	**CB**
***K* (95% cl)**	**1 (na)**	**0.62 (0.50-0.74)**	**0.57 (0.35-0.80)**	**0.92 (0.87-1.00)**	**1 (na)**	**1 (na)**	**1 (na)**
***Lw-k* (95% cl)**	**1 (na)**	**0.72 (0.64-0.81)**	**0.57 (0.38-0.79)**	**0.92 (0.87-1.00)**	**1 (na)**	**1 (na)**	**1 (na)**

95% CIs are reported close to each Cohen's kappa value.
ANC = agger nasi cell; CB = concha bullosa; CI = confidence interval; FB = frontal bulla; IFSSC = interfrontal sinus septal cell; Kuhn = type of Kuhn's cell; na = not applicable; Ra = radiologist; S1 = expert surgeon; S2 = beginning surgeon; SBC = suprabullar cell; SOEC = supraorbital ethmoidal cell.

Table 2: Cohen's kappa (κ) and linear weighted Cohen's kappa (Lw-κ) values of the anatomical variants of the agger-bulla for radiologist-vs expert surgeon matching (Ra vs S1) and in the beginner-vs-expert surgeons matching (S2 vs S1)

	Ra vs S1					
	M/l	**A**	**B**	**f**	**F**	**R**
***K* (95% cl)**	**1 (na)**	**0.84 (0.79-0.89)**	**0.73 (0.61-0.84)**	**0.81 (0.66-1.00)**	**1 (na)**	**1 (na)**
Lw-k (95% cl)	**1 (na)**	**0.88 (0.84-0.92)**	**0.80 (0.72-0.89)**	**0.87 (0.76-1.00)**	**1 (na)**	**1 (na)**
	S2 vs S1					
	M/l	**A**	**B**	**f**	**F**	**R**
***K* (95% cl)**	**1 (na)**	**0.96 (0.91-1.00)**	**0.86 (0.79-0.94)**	**0.81 (0.66-1.00)**	**1 (na)**	**1 (na)**
Lw-k (95% cl)	**1 (na)**	**0.96 (0.93-1.00)**	**0.85 (0.76-0.93)**	**0.87 (0.76-1.00)**	**1 (na)**	**1 (na)**

95% CIs are reported close to each Cohen's kappa value.
A = number of air spaces constituting the A complex; B = number of air spaces constituting the B complex; CI = confidence interval. f = presence or absence of a type f air space; F = presence or absence of a type F air space; Lw = linear weighted; m/l = medial or lateral position of the frontal sinus drainage pathway with respect to the uncinate process upper insertion; na = not applicable; R = presence or absence of a type R air space; Ra = radiologist; S1 = expert surgeon; S2 = beginning surgeon

4. Discussion

This study shows that the interrater agreement of ABC is higher than with the MBKC for both the air spaces anterior and posterior to the FSDP. However, the results were obtained in the ideal setting of radiological dissection with the contribution of expert radiologists and surgeons. Nevertheless, the high agreement between expert and novice surgeons suggests that the ABC can be efficiently applied even by non-experienced surgeons.

An ideal anatomical classification for ESS should be easy to apply in daily practice and provide information that is easy to memorize. In all endoscopic procedures to the frontal sinus, identification of the FSDP is the main target. Therefore, the basic information to be acquired is 3 configuration of FSDP **(Wormald, 2006)**.

Nonetheless, the 3D structure of FSDP is often difficult to construct secondary to several factors **(Daniels et al., 2003).**

First of all, it is not a real linear and regular pathway, as it would be intuitive to imagine, but it narrows and enlarges while ascending up to the frontal sinus, in relation to the shape and pneumatization of surrounding structures.

This forces the surgeon to infer the course of FSDP through the spatial relationship of surrounding spaces, thus increasing the chance to get disoriented. In this setting, the superior part of the UP represents the most important landmark guiding the surgeon to identify the FSDP. After removing the superior part of the UP, the surgeon, based on the information acquired by CT analysis, can safely place a probe into the FSDP.

This maneuver is usually enough to remove even the highest portion of the UP, and whether further ethmoidal air spaces are present or not, the frontal ostium is usually foreseen or directly seen, respectively. Nonetheless, the anatomical literature has focused more on several types of insertion of the UP rather than on the medial or lateral location of the FSDP in relation to UP upper insertion. On the contrary, **(Turgut et al., 2005).**

grouped the 6 types of UP insertion in the medial or lateral possible relations of the FSDP toward the UP; in particular, types I up to III correspond to a medial FSDP, while types IV up to VI to the lateral location. When compared with MBKC, ABC includes this information.

Many authors consider ANC as the key structure to understand the anatomy of the frontal recess, and therefore to approach the frontal sinus. However, different criteria are used to define the ANC **(Marquez et al., 2008)**.

An air space must have 2 features to be defined as ANC: it has to be a cell, which is a sphere-like air space with a drainage ostium smaller than the space diameter, and must lie within the bone of the agger nasi, which is a ridge of the frontal process of the maxillary bone being anterior to the middle turbinate insertion.

However, the term “ANC” is so deeply rooted in surgical culture that it seems difficult to overcome this misunderstood nomenclature. On the other hand, the surgeon must be aware that the most inferior air space of the anterior ethmoid can have several morphologies and should be opened at the beginning of the approach to the frontal sinus after performing vertical uncinectomy, regardless of its precise shape and extension. Thus, the definition of “air space” in the ABC could solve this problem, because it avoids further differentiation.

The number of air spaces to be opened is a far more important information to prevent incomplete removal of the bony lamellas surrounding the FSDP and subsequent relapse of sinus disease **(Huang et al., 2009).**

This is the reason why terms as “type 2,” “type 3,” or “type 4” Kuhn’s cell are inadequate, because they do not express the number of air spaces of the A complex that the surgeon should marsupialize.

A further limitation of the MBKC is the fact that the same name is used for different air spaces. For instance, FB is a SBC protruding into the frontal sinus along its posterior plate; this means that, despite optimal interrater agreement (Table.3), an air space overcoming for a few millimeters the posterior projection of the frontal sinus floor on the skull base and another air space reaching the top of the frontal sinus share the same name (Fig.38).

Type R air space was defined as a suprabullar recess extending from the frontal sinus to the basal lamella of the middle turbinate, without interposed bony septa. Even if a recent review of the sinonasal anatomical terminology has emphasized its surgical relevance, this air space is not described when using the MBKC **(Lund et al., 2014).**

Indeed, after removing the inferior air spaces of the B complex, the floor of a type R air space could resemble the fovea ethmoidalis, especially when hyperostotic changes are present. This may result in leaving behind a narrow space that is potentially scarring and leading to formation of a frontoethmoidal mucocele **(Lee et al., 2004).**

Therefore, the surgeon should identify this anatomical variant in advance in order to recognize the presence of a “false fovea ethmoidalis,” corresponding to the floor of the type R air space, and distinguish it from the actual fovea ethmoidalis.

The IFSSC, SOEC, FB, and CB showed optimal interrater agreement. The IFSSC acquires surgical relevance only when the cell extends from the frontal recess to interfrontal sinus septum. This configuration is much less frequent than an IFSSC arising directly from the frontal sinus **(Som and Lawson, 2008)**.

By applying ABC, the former configuration is considered as a medial frontoethmoidal cell, as suggested by other authors, and described as type f or F air space.

An IFSSC arising from the frontal sinus is identified after completing frontal sinusotomy.

When a SOEC is present, the corner between medial orbital wall and fovea ethmoidalis is pneumatized and can be easily used as endoscopic landmark for identification of the medial and cranial boundaries of B complex.

A CB should be detected both radiologically and endoscopically regardless of the classification system used, and frequently requires sagittal resection before starting any surgical procedure on the ethmoid and frontal sinus. Therefore, preoperative radiological assessment of IFSSC, SOEC, and CB is useful to the surgeon and should be integrated with the application of ABC.

Themajor limitation of this study is that it was performed in a preclinical setting where inflammatory modifications of the mucosa are not present. In patients with chronic rhinosinusitis air spaces of the frontoethmoidal area are often lined by thickened mucosa and polyps are frequently present, thus compromising their identification in CT images. Furthermore, at surgery bleeding can seriously decrease the ability to recognize air spaces.

This difficulty is increased in revision surgery, when the presence of scar tissue with partially marsupialized air spaces may limit the ability of both the radiologist and surgeon to identify residual cells. However, these flaws are typical of all anatomical classification systems of this area.

Another possible limitation of the study is that the familiarity on our part with the classification system might have increased the interrater agreement. Since the ABC showed promising results in this study, the next step of application in a clinical setting is already planned in order to assess possible limitations of the classification system and introduce consequent modifications.

Conclusion

Frontal sinus anatomy can be challenging even for the most experience surgeon. A thorough knowledge of the most common normal variants is critical in order to safely navigate through the nose during endoscopic sinus surgical procedures and avoid complications.

This preclinical study is, to the best of our knowledge, the first to introduce a new classification of the frontoethmoidal area by studying it through an objective and validated statistical method.

The ABC was developed to provide a more essential and practical classification system than the MBKC.

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