REVIEW

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Constant features of the adult maxillary bone in the site of the premaxillary suture: the *sutura notha*, Macalister's foramina, Parinaud's canal, and the second angle of the *canalis sinuosus* of Wood Jones

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Abstract

Developmental theories regarding the premaxillary (incisive) suture commonly overlook it separates the premaxillary and maxillary parts of the frontal process of maxilla. Thus, one would expect that neurovascular structures within this transitory mesenchymal zone to appear embedded within the adult frontal process of maxilla. The *sutura notha* (false suture, Weber's *sutura longitudinalis imperfecta*) is a poorly described, although constantly present, shallow groove in front of the anterior lacrimal crest, being perforated by a row of holes first described, to our knowledge, by Macalister, in 1884. Macalister's foramina should be discriminated anatomically from the accessory infraorbital foramina. Macalister's foramina lead into canals, usually described as vascular, within the frontal process. We demonstrate in cone-beam computed tomography that these canals, which correspond topographically to Parinaud's vascular canal, are connected, usually through a delicate intraosseous network, with Wood Jones' *canalis sinuosus* (*i.e.*, the ampullar angle of this canal located above the upper canine tooth). As this later carries the anterior superior alveolar nerve and artery, it is reasonable to consider that the canalar network within the frontal process of maxilla could serve for an accessory distribution of that nerve to the nasolacrimal duct, the atrium of the middle nasal meatus, the *agger nasi* cell, as well as to the infraorbital (prelacrimal) recess of the maxillary sinus.

Keywords: infraorbital canal, maxillary bone, anterior superior alveolar nerve, cone-beam computed tomography, nasolacrimal duct.

Introduction

Conventional textbooks of anatomy usually fail to describe morphological details, which, as we document further here, are lined up longitudinally in the area of the primitive premaxillary (incisive) suture. We review here, based on original cone-beam computed tomography (CBCT) evidence, these peculiar morphological traits, *i.e.*, the *sutura notha*, Macalister's foramina, Parinaud's canal, and their constant connection with Wood Jones' *canalis sinuosus*.

The premaxillary or incisive suture

The origin of the maxillary bone is a membranous one, and it is described to result from two ossification centers [1, 2], although this theory is disputed or denied by different authors, as reviewed by O'Rahilly & Gardner [3]. When two ossification centers are considered, the antero-medial one leads to formation of the premaxilla (or incisive bone, or intermaxillary bone, which carries the incisors), while the postero-lateral one corresponds to the postmaxilla or maxilla [1, 3]. Although the discovery of premaxilla was attributed to Goethe (1784), premaxilla being indicated as *os Goethei*, also Broussonet (1779) and Vicq d'Azyr (1780) came to the same result with different methods [4].

The premaxillary osseous tissue is seemingly of more recent deposition than that of the maxilla proper [3]. The existence of a skeletal element, however, does not depend on the presence of a separate ossification center [3]. Premaxilla and (post)maxilla unite very quickly in the area of the future canine alveolus, the limit of demarcation being the premaxillary (incisive) suture [1, 4]. Wood *et al.* (1969) concluded that "*The incisive suture should not be regarded as a true suture because it does not completely separate the upper jaw into anterior and posterior bones at any stage of development in the normal human embryo*" [5].

In actual textbooks of embryology, if mentioned, the premaxillary bone is depicted in a lingual view, showing a horizontal body, which is rostrally intercalated into the two palatine halves of the maxillary; however, the frontal, as well as the nasal processes of premaxilla are ignored [4]. The premaxillary bone forms the main boundary of

the *apertura piriformis* and in the adult, this part of premaxilla extends to the frontal bone to form a wedge between the maxillary and nasal bones [4]. Posterior to the frontal process of premaxilla, the frontal process of maxilla also extends upwards to the frontal bone, these two distinctive processes being initially separated by a broad mesenchymal space [4]. Authors which studied and reviewed the literature concerning the premaxillary bone [3, 4] ignored the *sutura notha* ("false suture"), which demarcates the two parts, anterior and posterior, of the frontal process [6] that result distinctively from the premaxilla and maxilla, and was firstly described, in our knowledge, by Macalister (1884) [7]. Unfortunately, the *sutura notha*'s description is missing from "Bergman's comprehensive encyclopedia of human anatomic variation" [8], as well as from "Gray's Anatomy" [9].

The *sutura notha* and Macalister's foramina

Macalister firstly described the *sutura notha*, or *sutura imperfecta*, in 1884 [7]. He wrote that it is "remarkably constant in some form or other, usually as a row of holes into which branches of the infraorbital artery pass" and presented this *sutura notha* in a couple of drawings that we reproduce in Figure 1.

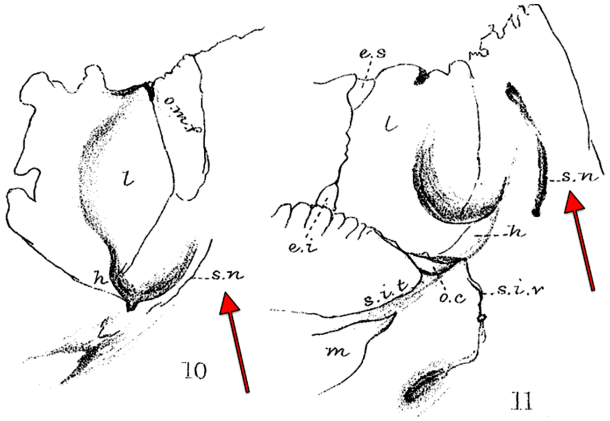

Figure 1 – ***Macalister's drawings in 1884 [7], depicting the* sutura notha *(s.n., superimposed red arrows).***

Macalister (1884) described that traces of *sutura notha*'s separateness sometimes continue inside of the maxilla, even when it is not so evident on the outside, and that not uncommonly *sutura notha* appears a fissure which completely traverses the bone, usually at its lower extremity [7]. This author described, by ignoring the lacrimal bone, which is normally placed between the ethmoid bone and the frontal process of the maxillary bone, that the *sutura notha* demarcates two distinct parts of the frontal process, one "which overlies the anterior border of the ethmoid" and other "which intervenes between the ethmoid and the nasal" [7]. The holes that Macalister described through the *sutura notha* will be further referred here as Macalister's foramina as he was the first, in our knowledge, to indicate them.

Flecker (1913) recommended the *sutura notha* should not be regarded as an articulating suture and described it as being produced by a small branch of the infraorbital artery, which grooves the frontal process of maxilla [10]. Therefore, the *sutura notha* is quite superficial and "does not penetrate" the entire thickness of the maxillary bone process [10]. Usually, it can be traced from the superior end of the nasolacrimal canal upwards, and it is very constant [10].

Whitnall (1932) [11], quoted by Burkat & Lucarelli (2006) [12], described that on the frontal process of the maxilla just anterior to the lacrimal sac fossa, a fine groove termed the *sutura notha* or *sutura longitudinalis imperfecta* of Weber, runs parallel to the anterior lacrimal crest and is a vascular groove through which twigs of the infraorbital artery pass through to supply the bone and nasal mucosa, and should be anticipated during lacrimal surgery to avoid bleeding.

Wobig & Dailey (2004) described the *sutura notha* as a shallow sulcus located just below the anterior lacrimal crest, in which a large nutrient foramen frequently exists; these authors wrote that *sutura notha* "may be related to the embryonic facial fissure" [13], which is *bona fide* the upper segment of the premaxillary (incisive) suture at the junction between the two segments, premaxillary and maxillary, of the frontal process of the maxillary bone. Wobig & Dailey (2004) discuss that often, in lacrimal sac surgery, the margins of the *sutura notha* are mistaken for the anterior lacrimal crest.

Isloor (2014) described in its "Lacrimal drainage surgery" textbook that *sutura notha* is a bony groove which runs parallel, "4 mm lateral to the anterior lacrimal crest" and separates "the frontal process of maxilla and lacrimal bone" [14]. Isloor details that periosteum is tightly adherent to *sutura notha* [14] and that *sutura notha* is a vascular groove through which pass small twigs of the infraorbital artery [15]. However, between the lacrimal bone and the frontal process of maxilla is just the lacrimo-maxillary suture, and in any case not the *sutura notha*, which is placed anterior to the anterior lacrimal crest. We will refer to this further as the inconsistency of Isloor (2014).

The anatomical features of the *sutura notha* and Macalister's foramina are presented in the three-dimensional (3D) volume renderization of the maxillary bone in Figure 2.

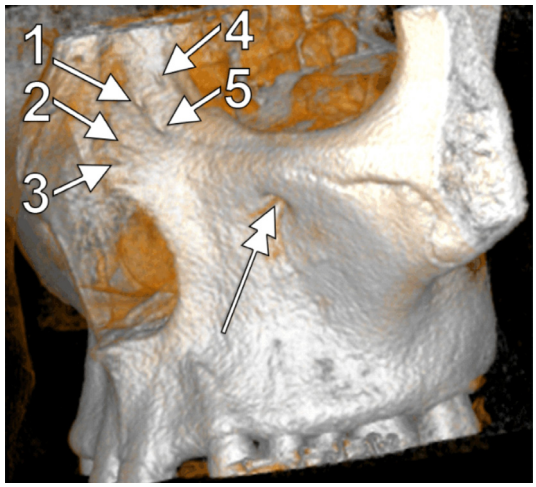

Figure 2 – ***Three-dimensional volume renderization (iCatVision software and the related application 3DVR v5.0.0.3, Transparent Skin Filter) of the left maxillary bone, antero-infero-lateral view. Five foramina of Macalister are identified (1–5) on the frontal process, two of these (1 and 5) being located on the* sutura notha*. The double-headed arrow indicates the infra-orbital foramen.***

It can be observed there that Macalister's foramina are not exclusively present in the vascular groove designated as *sutura notha*. Although their number was individually variable, we found in all the cases we documented in CBCT the Macalister's foramina leading into canals within the frontal process of the maxillary bone.

Recently, Zhang *et al.* (2019) discussed that Macalister's foramina may have particular surgical relevance, as they may explain the occasional brisk intraoperative bleeding noted from this region [16].

Inconsistencies in descriptions of *sutura notha*

Despite the fact that Flecker (1913) [10] clearly wrote that *sutura notha* is not penetrating the bone, Mann *et al.* (2016) [6] wrote that this suture "was once believed to be an articulation that penetrated the full thickness of the bone (Flecker 1913)", which denaturates Flecker's description.

Although Wobig & Dailey (2004) [13] just reasonably related the *sutura notha* to the embryonic facial fissure, Mann *et al.* (2016) wrote that the *sutura notha* has been described by Wobig & Dailey (2004) "as an embryonic facial fissure", which is not exact.

The inconsistency of Isloor (2014) was quoted by Mann *et al.* (2016) in their "Photographic regional atlas of non-metric traits and anatomical variants in the human skeleton" when they indicate that *sutura notha* is described as "a groove that separates the frontal process of the maxilla and the lacrimal bone (Isloor 2014)" [6]. The inconsistency of Isloor (2014) continued in Mann *et al.* (2016), is further continued by Zhang *et al.* (2019) when they indicate that the *sutura notha* is a vascular groove "separating the frontal process of the maxilla from the lacrimal bone", which contains small twigs of the infraorbital artery supplying the bone and nasal mucosa [16]. Zhang *et al.* (2019) also gave credit to Hwang *et al.* (2015) for that description of the *sutura notha*, but in the cited paper, the term "*notha*" does not exist [17].

Interestingly, although the study of Macalister (1884) on the varieties and morphology of the lacrimal bone is largely cited in the atlas of Mann *et al.* (2016), it was not used as reference when the *sutura notha* was presented.

The infraorbital artery and the *sutura notha*

All authors who described the *sutura notha* indicated it is perforated by small twigs of the infraorbital artery [6, 7, 10, 11, 13, 16]. This artery exits through the infraorbital foramen on the anterior face of the maxillary bone to supply branches to the skin and mucosae [18]. When exiting the infraorbital foramen, the branches of the infraorbital artery were found in a periosteal layer [19]. The distribution patterns of the infraorbital artery were classified into five types (I–V); in types I–IV, the infraorbital artery sends off an upward nasal branch to the nasal mucosa anastomosing to the angular artery [18, 20], the terminal branch of the facial artery. Therefore, two arteries supply the *sutura notha* region, a periosteal one, supplied by the infraorbital artery, and a supraperiosteal one, the angular artery. Therefore, both of these are reasonable suppliers of Macalister's foramina, although the infraorbital artery-deriving twigs covered at this level by the *orbicularis oculi* muscle are the better candidates. The infraorbital artery remains as unique provider for the Macalister's foramina in cases with absent angular arteries (non-angular types of facial artery). In these regards, finding foramina in front of the anterior lacrimal crest, which are supplied by canals, or semicanals, deriving from the infraorbital canal (Figure 3), will recommend these foramina to be regarded as Macalister's foramina, rather than as accessory infraorbital foramina.

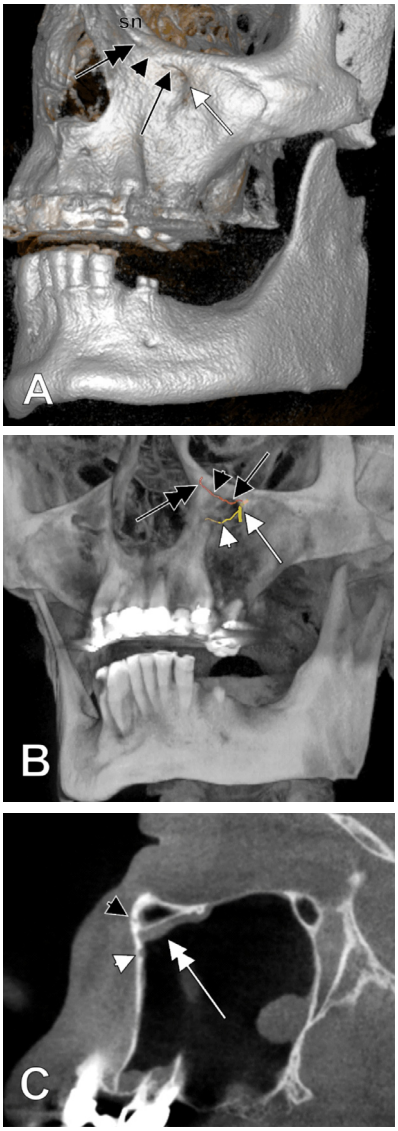

Figure 3 – ***(A) Three-dimensional volume renderization (iCatVision software and the application 3DVR v5.0.0.3, Sinus/Bone Filter) of the left maxillary bone, infero-lateral view. (B) Three-dimensional volume renderization (Planmeca Romexis Viewer 3.5.0.R software, B&W X-Ray Filter) of the left maxillary bone, antero-infero-lateral view. (C) Sagittal slice through the left maxillary sinus. The left infraorbital canal (double-headed white arrow) opens at the respective infraorbital foramen (white arrow), which is located beneath the infraorbital margin. From the infraorbital canal leaves the*** **canalis sinuosus** ***(white arrowhead) coursing within the bone beneath the infraorbital foramen. From the medial border of the infraorbital margin leaves a semicanal (black arrow), further continued as canal (black arrowhead), which finally opens at a Macalister's foramen (double-headed black arrow) at the lower end of the*** **sutura notha** ***(sn), in front of the anterior lacrimal crest. B&W: Black & White.***

These canals which derive from the infraorbital canals to supply Macalister's foramina rather have a vascular content – the nasal branch of the infraorbital artery which, instead of a periosteal course, it has an intraosseous one.

Parinaud's canal

The premaxillary suture was described as reaching, superior to the *crista conchalis* and almost at the level of the nasolacrimal canal, the *arteria angularis* canal or Parinaud's canal [1]. Parinaud's canal is *bona fide* supplied through Macalister's foramina in the *sutura notha* area but this raises questions whether the term "*arteria angularis* canal" is adequate, or it should be changed to "*arteria infraorbitalis* canal". Nevertheless, we found at least one vertical canal connected to the foramina in the area of *sutura notha*; when multiple canals are present, they could be termed the canals of Parinaud. The weak point here is that we could find no evidence of the exclusively vascular content of such canals, neither in the works describing the *sutura notha*, nor in the study we used here to document Parinaud's canal.

The *canalis sinuosus* of Wood Jones and its second angle

The *canalis sinuosus* was described in 1939 by Frederic Wood Jones [21] and it carries the anterior superior alveolar nerve, which is distributed mainly in the frontal (anterior) maxillary teeth [22]. The anterior superior alveolar nerve is usually accompanied by a small artery, the anterior superior alveolar artery [23], branched from the infraorbital artery.

According to Wood Jones' description, to which different authors subscribed [22–28], the *canalis sinuosus* has an initial infraorbital course, then it turns medially to continue with a transverse facial segment located in the anterior wall of the maxillary sinus [21]. The medial end of the transverse facial segment of *canalis sinuosus*, somewhat dilated (ampullar angle), is constantly located at the level of *crista conchalis*, which attaches the inferior nasal turbinate, as well as at the level of the lower end of the nasolacrimal canal [21]. Further, the *canalis sinuosus* continues with a third segment, initially located within the margin of the *apertura piriformis*, between the medial aspect of the alveolus for the canine tooth and the nasal cavity [21]. Therefore, the medial end of the transverse facial segment, as well as the initial part of the third, circumnarial segment of *canalis sinuosus*, topographically correspond to the premaxillary suture, as also Parinaud's canals do. Wood Jones (1939) also observed that "communicating with the dilatation of the medial end of the transverse facial portion of the canal, there is often a foramen which issues on the lateral side of the facial aspect of the narial margin, about half way, or even considerably higher, up the narial orifice". He further specified that "This canal appears to be entirely vascular, no branch of the nerve having been traced to it" [21]. One should trust here the statement of Wood Jones (1939), as he used only drawings to support his descriptions. In a recent dissection study, von Arx & Lozanoff (2015) confirmed the anatomy of the *canalis sinuosus* [23], mostly as described in Wood Jones' drawings (1939). However, the two authors did not focus, or observe, Parinaud's vertical canals connected with the second angle of the *canalis sinuosus*.

Therefore, although not indicating Parinaud's eponym, Jones identified that the medial end of the transverse facial portion of *canalis sinuosus* communicates with the canal of Parinaud. We did the same in all our CBCT cases, the Parinaud's and Wood Jones' canals being presented in Figure 4, after being 3D digitally reconstructed.

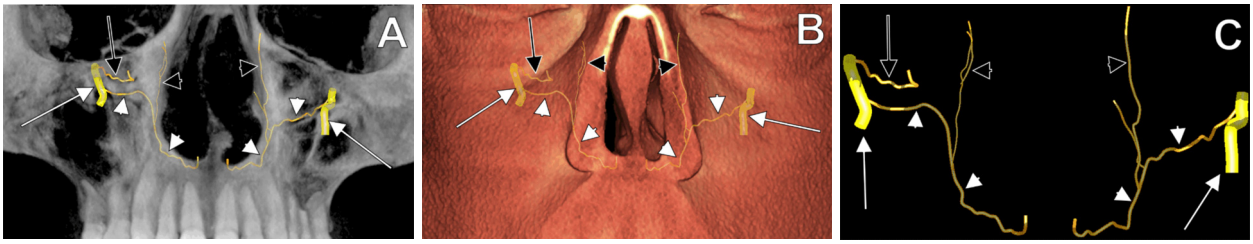

Figure 4 – ***Three-dimensional volume renderizations, anterior views of the midface, Planmeca Romexis Viewer 3.5.0.R software: (A) B&W X-Ray Filter; (B) Soft Tissue Filter; (C) B&W X-Ray Filter with complete bone subtraction. There are indicated the infraorbital canals (white arrows), a left accessory infraorbital canal (black arrow), the* canalis sinuosus *(white arrowheads), and the canals of Parinaud (black arrowheads). B&W: Black & White.***

In Figure 3, it can also be observed an accessory infraorbital canal, which derives from the infraorbital canal and opens at an accessory infraorbital foramen. Anatomic variations of the infraorbital foramina number should be carefully discriminated from the constant Macalister's foramina. This should be easy, as the former are located inferior to the infraorbital margin and are supplied by canals deriving from the infraorbital canal, while the latter supply Parinaud's canals connected to the *canalis sinuosus*. A foramen which is far distanced medially from the infraorbital foramen, and is located in front of the anterior lacrimal crest, is a Macalister's foramen, even it is connected with the infraorbital canal (Figures 3 and 5). Zhang *et al.* (2019) distinguished accessory infraorbital foramina located near the main one from accessory infraorbital foramina "occurring along the *sutura notha*" but they failed to identify these later as Macalister's foramina [16]. However, they adequately observed that "none of the accessory foramina arising from the *sutura notha* showed connectivity with the infraorbital foramen" [16].

The network of canals within the human adult frontal process of the maxillary bone is supplied by Wood Jones' and Parinaud's canals

CBCT was not previously used to study the canals within the frontal process of maxilla. Therefore, although foramina were easily observed on dry bones, the intraosseous canals were poorly documented. In our samples, we gathered evidence that within the frontal process of maxilla and in the topographic site of the premaxillary

suture (above the canine and between the canine and the lateral incisor), numerous canals of variable size are interconnected, thus building an intraosseous network (Figure 6). That network was invariably connected with the second angle of the *canalis sinuosus*, thus extending from the *sutura notha* area to the level of *crista conchalis* and the anterior attachment of the inferior nasal turbinate.

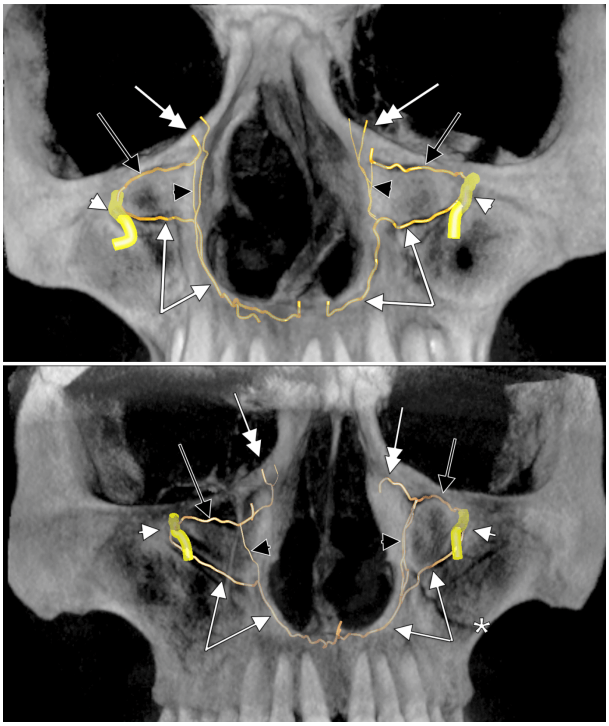

Figure 5 – ***Three-dimensional volume renderizations of two different cases (adult female patient in the upper panel and adult male patient in the lower one), anterior view of the midface (Planmeca Romexis Viewer 3.5.0.R software, B&W X-Ray Filter). There are bilaterally indicated the infraorbital canal (white arrowheads), sinuous canal (white arrows), accessory infraorbital canal (black arrows), Parinaud's canals (black arrowheads) and the foramina of Macalister in the area of the* notha *suture (double-headed white arrows). The lateral antral canal (*) is indicated in the lower panel. B&W: Black & White.***

The anatomic possibilities of distribution through the network of the premaxillary suture

Unless checked by microdissections or by specific microvascular injection techniques, the canals within the frontal process of maxilla, which are found in CBCT, should be regarded as potentially neurovascular. While the foramina of Macalister were considered to have a vascular content, but without supporting evidence, the connection with the *canalis sinuosus* could use for branches deriving either from the anterior superior alveolar nerve, or from its artery. The network of canaliculi within the frontal process of maxilla should be regarded as neurovascular and possibly distributed to neighbor spaces (Figures 7 and 8) lined with mucosae. These include the atrium of the middle nasal meatus, the nasolacrimal duct, and variably present air spaces, such as the *agger nasi* air cell within the frontal process of maxilla [29] and the prelacrimal (infraorbital) recess of the maxillary sinus [30].

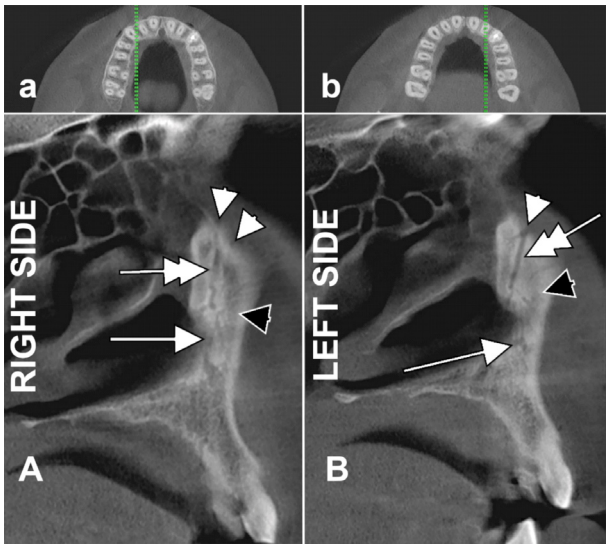

Figure 6 – ***CBCT multiplanar reconstructions. On axial slices (a and b), the sagittal cuts are located in the sites of the premaxillary sutures. On sagittal slices (A and B), there are demonstrated the canals contributing to the network (black arrowheads) within the frontal processes of the maxillary bones. The foramina of Macalister (white arrowheads) are the upper openings of the Parinaud's canals (double-headed arrows). These later, as well as the canals of Wood Jones (arrows) contribute the anastomotic network within each frontal process. CBCT: Cone-beam computed tomography.***

The potential neural content of Macalister's foramina could explain why failures of anesthesia during external dacryocystorhinostomy (DCR) occur. McNab & Simmie (2002) observed in several patients, who received local anesthesia for external DCR, they all complained at the time of removal of bone in the upper portion of the nasolacrimal canal, below the lacrimal fossa itself [31]. The two authors discussed that it is possible that these patients may have had this area innervated by a nerve not blocked by the usual technique, the anterior superior alveolar nerve [31]. They observed that supplementary infiltration over the adjacent bone and into the underlying nasal mucosa allowed satisfactory completion of the procedure [31]. Therefore, although not supported by the anatomical background at that time, McNab & Simmie (2002) clinically demonstrated the distribution of the anterior superior alveolar nerve, through the network within the frontal process of maxilla, to the nasolacrimal canal.

Materials and Methods

For this pictorial review, we retrospectively documented 300 archived files of patients (170 females and 130 males) who had undergone dental CBCT scans. The patients were between 27 and 81 years old. Subgroups were used in previous studies [32–35], the patients being scanned with an iCat CBCT machine (Imaging Sciences International, Hatfield, PA, USA) using the following settings: resolution 0.25, field of view 130, image matrix size 640×640, sensor dimensions 20×25 cm, and grayscale resolution 14 bits. The voxel dimension was set on 0.25 mm and the acquisition time on 13.9 seconds. The files were evaluated with the iCatVision specific software and 3D volume renderizations resulted by use of its associated application

(3DVR Volume Renderer). Then, the files were converted in a Digital Imaging and Communications in Medicine (DICOM) format, as in other previous studies [22, 29, 36–39], and were also evaluated using the Planmeca Romexis Viewer 3.5.0.R software. The patients' maxillae were investigated in two-dimensional multiplanar reconstructions (MPRs): axial, coronal and sagittal, as well as on 3D volume renderizations.

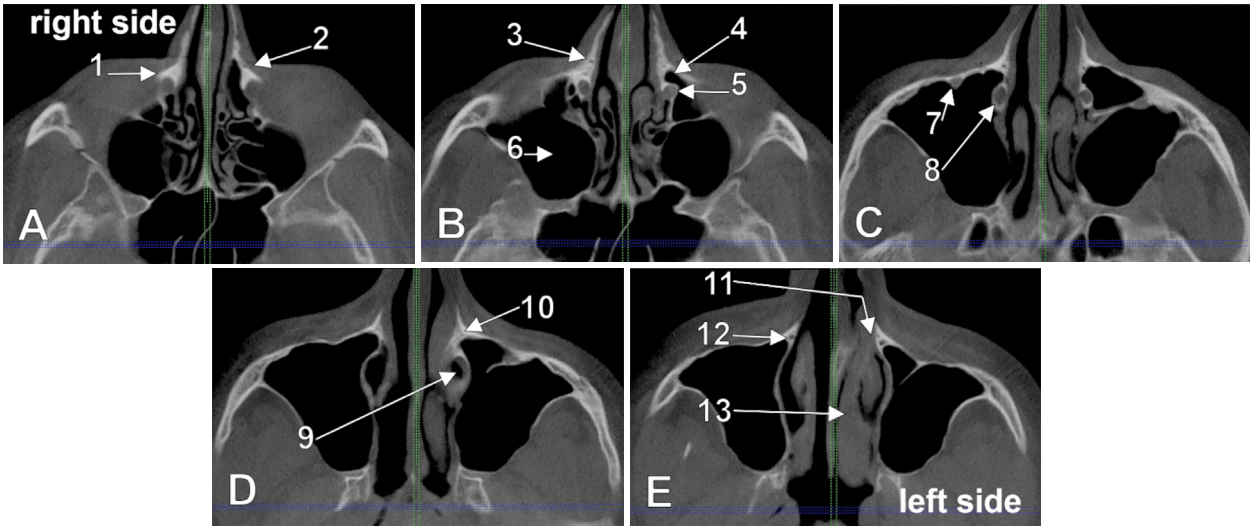

Figure 7 – ***(A–E) Superior-to-inferior series of axial slices presenting the topography of the canals through the frontal process of the maxillary bone. 1: Anterior lacrimal crest; 2: Foramen of Macalister; 3: Canal of Parinaud; 4: Prelacrimal or infraorbital recess of the maxillary sinus; 5: Superior end of the nasolacrimal canal; 6: Maxillary sinus; 7: Infra-orbital canal; 8: Nasolacrimal canal; 9: Inferior end of the nasolacrimal canal; 10: Intraosseous network of canals; 11:*** **Crista conchalis*****; 12: Sinuous canal; 13: Inferior nasal turbinate.***

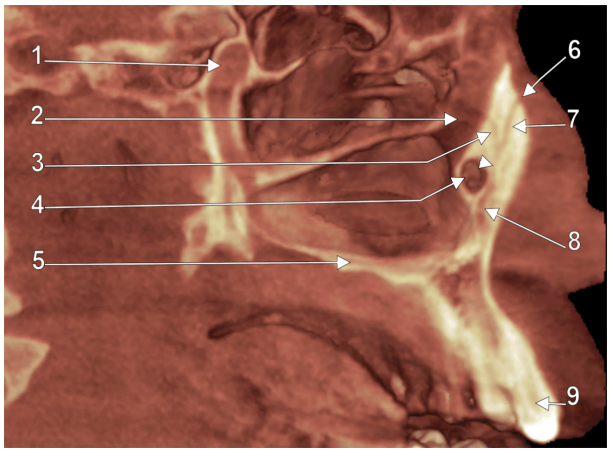

Figure 8 – ***Three-dimensional volume renderization (Planmeca Romexis Viewer 3.5.0.R software, Soft Tissue Filter). Sagittal cut through the left lateral nasal wall, medial view. 1: Pterygopalatine fossa; 2: Naso-lacrimal canal; 3:*** **Canaliculus** ***for the nasolacrimal duct; 4: Prelacrimal recess of the maxillary sinus; 5: Hard palate; 6: Foramen of Macalister; 7: Canal of Parinaud; 8:*** **Canalis sinuosus** ***of Wood Jones; 9: Upper left lateral incisor.***

Conclusions

The *sutura notha* and Macalister's foramina lie in the anatomical situs of the premaxillary (incisive) suture and should be carefully distinguished anatomically to avoid bleeding, or to better understand the complete possible distribution of the anterior superior alveolar nerve and artery.

Conflict of interests

All authors declare that there is no conflict of interests.

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