ORIGINAL ARTICLE

Radiological Anatomy of the Ethmoidal Arteries: CT Cadaver Study∗

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Abstract
Introduction and objectives: Our aim was to study the radiological anatomy of the ethmoidal arteries.
Methods: A descriptive study was performed including CT images of 20 cadaver heads. The specimens were perfused with a radiopaque material and various anatomical parameters were analysed.
Results: The anterior ethmoidal artery was found in 95% (38/40) of cases. It originated from the ophthalmic artery in 87.5% (34/40) of nasal cavities. In 6 cases, normal variants were found. The mean length of the anterior ethmoidal canal was 8.43 ± 0.74 mm. The angle performed into the skull base was 37.3 ± 5.48 °. In 90% of cases (36/40), it was located between the second and third lamella. The posterior ethmoidal artery was localised only in 14/40 cases, with 28.5% (4/14) of them showing normal variants. The mean length of the posterior ethmoidal canal was 7.1 ± 1.02 mm. The angle performed into the skull base was 7.11 ± 4.07 °. The distance from sillon to the anterior ethmoid artery was 55.51 ± 5.52 mm. The angle between the nasal spine and the anterior ethmoidal canal was 57.67 ± 1.68 °. The distance between the nasion and the anterior ethmoidal canal was 29.31 ± 2.53 mm, the distance was 11.24 ± 2.14 mm from the anterior ethmoid artery to the posterior ethmoid artery and from the posterior ethmoid artery to the optic nerve, 7.26 ± 1.33 mm. Supraorbital cells were observed in 15% (6/40) of the cases.
Conclusions: A complete vascular study of the ethmoidal arteries was possible by using this technique.
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Introduction

Endoscopic sinus surgery has undergone significant progress from its beginnings in Austria, barely 50 years ago, until our days. 1

The pillars of this rapid development are better knowledge of the surgical field, improvements in the materials used during surgery, and, primarily, the great forward impulse that imaging techniques have represented, with the plain radiographs used in the 70s having been effectively replaced by the computed tomography (CT) techniques used at present.2,3 Recent advances in CT and three-dimensional reconstructions enable visualisation of anatomical details that were impossible before. It is now possible to recognise the paths of 2 major anatomical structures and surgical references: the anterior and posterior ethmoidal arteries.

The anterior ethmoidal artery (AEA) in particular is one of the most notable endoscopic references, marking the posterior limit of the frontal recess. Similarly, in external approaches, its identification in the frontoethmoidal suture marks the limit of the anterior skull base.

In its path, the AEA crosses 3 cavities: the orbit, the ethmoidal labyrinth, and the anterior cranial fossa. It enters the olfactory fossa through the ethmoidal groove, located in the lateral lamella of the cribriform plate, the point of maximum fragility of the entire skull base and the place where cerebrospinal fluid fistulas and postoperative encephalocoele most often occur.5 Knowing its anatomy and being able to identify its path in imaging studies helps to avoid iatrogenic damage.

The radiological anatomy of the ethmoidal arteries has been widely studied.4,6-12 Most works published refer to CT observations of the anterior and posterior ethmoidal canals themselves. However, due to the technical limitations of the scanner, their arterial contents and the intra-orbital and intra-cranial segments have hardly been referenced.

The aim of this article is to present a study of the radiological anatomy of the anterior (AEA) and posterior ethmoid (PEA) arteries by CT images in the perfused cadaver. We aim to define the characteristics and anatomical references of each of their segments and present variants from normality.

Material and Methods

We carried out a descriptive study with CT images obtained from 40 nasal fossae from 20 cadaver heads. We used cadavers from the dissection room at Miguel Hernández School of Medicine. The specimens were initially prepared and preserved according to the Thiel’s13 technique and their vessels perfused with latex according to Thiel.14

Next, we performed a CT scan of the paranasal sinuses of all specimens in the sample using a multidetector CT, SOMATOM Sensation 10® model (Siemens), with a collimator of 0.75 mm, 120 kV, and 100 mAs, as well as a table speed (pitch) of 0.45 and 10 crowns.

We obtained axial sections of 1 mm between the top of the frontal sinus and the hard palate and carried out reconstructions with an overlap of 0.75 mm. Subsequently, we obtained coronal and sagittal planes from the axial images, with multi-planar reconstructions and post-processed them with two-dimensional techniques such as the Maximum Intensity Projection (MIP).

Images were analysed by a single observer, a radiologist, who studied the following parameters: presence of AEA and of PEA, origin of AEA and of PEA, presence of supra-orbital...
cells, distance from nasal spine to anterior ethmoidal canal, angle between nasal spine and AEA, distance from nasion to anterior ethmoidal canal, location of the AEA according to the ethmoidal lamellae, distance from AEA to PEA, distance from PEA to optic nerve, length of the artery along the anterior ethmoidal canal, angle of entry into the skull base, and angle of exit into the skull base of the PEA.

To establish the distance between the nasion and the AEA and between the nasal spine and the AEA, we angled an axis that passed through the midline, by the AEA at the level of its entry point into the skull base in the axial and coronal planes. Subsequently, measurements were taken in the sagittal plane (Fig. 1A). In the same plane, we also measured the angle formed by an imaginary line connecting the nasal spine with the AEA and another horizontal one passing through the nasal spine and the hard palate.

The length of the anterior ethmoidal canal and the posterior ethmoidal canal and the angle formed by the arteries at their entry point with respect to the skull base were obtained through axial sections (Fig. 1B). The distance between the AEA and the PEA and the optic nerve was recorded in axial and sagittal planes (Fig. 2A). The location of the AEA with respect to the ethmoidal lamellae was studied in sagittal plane, considering the uncinate process as the first lamella, the ethmoid bulla as the second lamella, the base plate of the middle turbinate as the third, and the plate of the superior turbinate as the fourth; lastly, the fifth lamella, being inconstant, would correspond to the plate of the superior turbinate (Fig. 2B).

The records obtained were stored in a database. The statistical analysis employed absolute and relative frequencies for qualitative variables (presence of AEA and of PEA, origin of AEA and PEA, location of AEA according to lamellae, and presence of supra-orbital cells) and measurements of central tendency and dispersion for quantitative variables (remaining variables). We used Student's t-test for comparison of quantitative variables between both sides. As alpha error probability, we took the value of .05. This statistical analysis was carried out using the SPSS11 software program.

Results

The AEA was located in 1 of its 3 segments in 95% (38/40) of cases, while the identification of the PEA could only take place in 14 of the 40 fossae (35%).

In 87.5% (35/40) of the fossae, the AEA originated from the ophthalmic artery, with the remaining 5 cases being variations from normality: the AEA was absent in both fossae in 1 specimen (Fig. 3A) and the AEA and PEA arteries emerged from a common ethmoidal artery, itself a branch of the ophthalmic artery, in another 3 cases (Fig. 3B).

The path of the AEA along the anterior ethmoidal canal had a mean length of $8.43\pm0.74$ mm (mean ± SD), forming an angle before its exit from the orbit of $37.3\pm5.48^\circ$, with a range between $27^\circ$ and $37^\circ$ (Fig. 1B).

The PEA could only be located in 35% (14/40) of the fossae. Of these, 21.4% (3/14) presented variants from normality in their origin. In these 3 fossae, we observed an exit of the PEA from a common ethmoidal artery (Fig. 3B). The mean length of its path along the posterior ethmoidal canal was somewhat lower, with this figure being estimated at $7.1\pm1.02$ mm. Its path in this segment maintained a more horizontal direction, with an anterior angle of $7.11\pm4.07^\circ$ at its exit from the orbit (Fig. 1B).

The distance from the nasal spine to the AEA was $55.51\pm5.52$ mm. The angle between an imaginary line connecting the nasal spine with the anterior ethmoidal canal and a horizontal line passing through the nasal spine was $57.67\pm1.68^\circ$ (Fig. 1A).

The study of AEA location with respect to the lamellae could be performed in 36 of 40 fossae. In 100% of the cases studied (36/36), the AEA was located between the second and third lamella (Fig. 2B). In 5% (2/40) of cases, the artery could not be located in the sagittal sections and the artery was absent in the remaining 5% (2/40).

We measured the distance from the nasion to the anterior ethmoidal canal in the sagittal plane. This was $29.31\pm2.53$ mm (Fig. 1A). The mean distance from the AEA...
to the PEA was $11.24 \pm 2.14$ mm and, from the PEA to the optic nerve, it decreased to $7.26 \pm 1.33$ mm.

We observed supra-orbital cells in $15\%$ ($6/40$) of the fossae.

The quantitative variables were analysed independently on the right and the left sides and the results were compared between the two. Differences found were not statistically significant in any of the parameters studied.

The results of the measurement are summarised in Tables 1-3.

Discussion

Ethmoidal arteries originate from the ophthalmic artery. The latter emerges in most cases from the supraclinoid portion of the internal carotid artery and goes into the orbit through the optic foramen in a lateral arrangement to the 2nd cranial nerve.15 After starting its intra-orbital path, the ophthalmic artery crosses the orbit from lateral to medial above the optic nerve and lies in a medial position within it.15 In 90% of cases, the AEA originates from the most distal region of the ophthalmic artery in the anterior third of the orbit16 (Fig. 4A).

After its exit, it advances a few millimetres in an anterior direction, then makes an anterior convex loop below the superior oblique muscle and returns about 5 mm backwards seeking the anterior ethmoidal canal on the frontoethmoidal suture (Fig. 4B).17 With an approximate diameter of $0.92$ mm,16 its intra-orbital path is estimated to have a distance of $25$ mm, with this figure varying according to its origin and according to the location of the anterior ethmoidal canal.17

In almost all the fossae ($35/40$) in our series, the AEA originated in the ophthalmic artery. However, in 3 cases, it originated from a common ethmoidal artery (in turn a branch of the ophthalmic artery), from which the PEA also emerged (Fig. 3B). In 1 specimen, the AEA was absent on both sides. These variants, already widely described by Lang and Schäfer17 in 1979, could be observed in our study due to the technique employed, which showed anatomical details of the intra-orbital segment on the CT scan.
The AEA leaves the orbit through the anterior ethmoidal canal on the frontoethmoidal suture to enter the anterior ethmoidal canal. At this level in the coronal sections of the CT, it is possible to observe a pyramid-shaped notch in the medial wall of the orbit, which corresponds to the exit of the artery between the superior oblique and the internal rectus muscles; this constitutes the most constant anatomical reference for its location in the scan.\textsuperscript{4,11} In our study, we could clearly observe the exit point of the artery (Fig. 4B).

Most published studies have extensively evaluated the course of the AEA in the ethmoidal labyrinth. In the late

<table>
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<th>Table 1</th>
<th>Summary of Results of Quantitative Variables.</th>
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<tbody>
<tr>
<td>Variables</td>
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<td>Angle nasal spine-AEA</td>
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<tr>
<td>Distance nasion-AEC</td>
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<td>Distance AEA-PEA</td>
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<tr>
<td>Distance PEA-optic nerve</td>
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<tr>
<td>Length of PEC</td>
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<tr>
<td>Angle of AEA in skull base</td>
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</tr>
<tr>
<td>Angle of PEA in skull base</td>
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</tbody>
</table>

AEA: anterior ethmoidal artery; AEC: anterior ethmoidal canal; PEA: posterior ethmoidal artery; SD: standard deviation.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of Results of Qualitative Variables.</th>
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<tr>
<td>Presence of PEA</td>
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<td>Origin of AEA</td>
<td>92.1% (35/38)</td>
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<td>In ophthalmic artery</td>
<td>7.9% (3/38)</td>
</tr>
<tr>
<td>Origin of PEA</td>
<td>78.6% (11/14)</td>
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<td>In ophthalmic artery</td>
<td>21.4% (3/14)</td>
</tr>
<tr>
<td>Presence of supra-orbital cells</td>
<td>15% (6/40)</td>
</tr>
<tr>
<td>Location by lamellae</td>
<td>100% (36/36)</td>
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</tbody>
</table>

AEA: anterior ethmoidal artery; PEA: posterior ethmoidal artery.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Comparative Study Between Both Fossae.</th>
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<td>Angle spine-AEA</td>
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</tr>
<tr>
<td>Left</td>
<td>19</td>
</tr>
<tr>
<td>Distance nasion-AEC</td>
<td>19</td>
</tr>
<tr>
<td>Left</td>
<td>19</td>
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<tr>
<td>Distance AEA-PEA</td>
<td>17</td>
</tr>
<tr>
<td>Left</td>
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</tr>
<tr>
<td>Distance PEA-OPT N.</td>
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<td>Left</td>
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<tr>
<td>Length of AEC</td>
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<tr>
<td>Left</td>
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<tr>
<td>Angle AE-skull base</td>
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<td>Length of PEC</td>
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<td>Angle PEA-skull base</td>
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</table>

AEA: anterior ethmoidal artery; AEC: anterior ethmoidal canal; OPT N.: optic nerve; PEA: posterior ethmoidal artery; PEC: posterior ethmoidal canal.
70s, Lang and Schäfer12 described its oblique direction along the skull base. Subsequently, other publications have corroborated this datum.16,18-21 Moon et al.19 mentioned the diagonal path, from lateral to medial, in all 70 specimens in their sample and Floreani et al.,20 reported that the artery left the orbit making an anterior angle of 30-45° towards the ethmoidal groove. The data collected in our study agreed with those previously published in cadaver dissections and adjusted to a mean of 37.3±5.48°, with a range between 27° and 37° (Fig. 4A).

In agreement with other studies,16,19,21,22 the AEA was located between the 2nd and the 3rd lamella in most cases in our series (36/40) (Fig. 2B). In 5% (2/40) of cases, the artery could not be located in the sagittal sections and the artery was absent in the remaining 5% (2/40) (Fig. 3A). This is a constant datum in the literature, already described by Han et al.,21 Kirchner et al.,23, and Araujo et al.,18 who established AEA absences of 4%, 7%, and 8% of cases respectively.

Throughout its path, the anterior ethmoidal canal may present partial or total dehiscence, thus increasing the risk of damage during surgery. There is some disagreement in this respect in the literature. While Moon et al.19 established 11% of dehiscent canals, other authors such as Minningerode24 or Kainz and Stammberger3 pointed to a higher incidence, of around 40%. Araujo et al.18 attributed the 67% incidence of dehiscent canals found in their work to possible racial differences between studies. Such discordant data could be explained by differing working methodologies, assuming that in some cases such dehiscence could be related to the exit or entry points of nerves. The characteristics of our study did not allow us to evaluate these parameters.

Another point of controversy is the relationship of the AEA with respect to the skull base. Basak et al.7 used coronal CT sections for their study in living patients; these researchers observed that the AEA crossed the anterior ethmoid freely in 43% of cases, while it passed through the ethmoidal labyrinth attached to the skull base in the remaining 57%. Kainz and Stammberger3 stated that, in most cases, the AEA was connected to the skull base by a mesentery of about 5 mm. Contrary to this, in Moon et al.’s19 study, about 90% of the arteries were attached to the skull base. Once again, this controversy could be due to racial differences or differences in study techniques. Within this controversy, Floreani et al.,20 established a strong correlation between the length of the vertical lamella and the presence of a mesentery in the anterior ethmoidal canal, stating that when the depth of the olfactory fossa was greater than 4 mm (Keros grade II or III),25 there was a relative risk of up to 17.3 with 95% CI (2-150) that the AEA would be anchored to the skull base by a mesentery. In turn, Simmen et al.,22 and Souza et al.,11 established a statistically-significant association and stated that, in the presence of supra-orbital cells, the AEA freely crosses the ethmoid, not being anchored to the skull base. We found that this figure was confirmed in 15% (6/40) of cases in which supra-orbital pneumatisation was observed.

Due to its location, in the posterior edge of the frontal recess, the AEA represents a major anatomical landmark that helps to locate the skull base during surgery.19 Until a few years ago, the AEA was identified using the maxillary line,23 the lamina cribosa19 or the middle turbinate axilla as notable anatomical references. Subsequently, other points of interest were developed: the mean distance between the nasal spine and the AEA in our study was 55.51±5.52 mm and the angle between the nasal spine and the AEA and a horizontal line passing through the spine was 57.7±1.78° (Fig. 1A). These measurements are very similar to those found by Moon et al.,19 and Araujo et al.18 Some authors have compared the distance between the nasal spine and the AEA by gender. Araujo et al.,18 established asymmetry between males and females, with the distance being somewhat greater in males than in females. This difference, although statistically significant in their study, has not been confirmed by other authors.26

In the 38 fossae in which we studied the distance between the nasion and the AEA, the mean distance was 29.31±2.5 mm (Fig. 1A). This figure is similar to that published by Cankal et al.6 in a CT scan study and is a useful reference for the treatment of some tumoral causes by external approaches or for uncontrollable epistaxis in which the endoscopic AEA ligation is not possible. However, it is also true that the external incision is made in the inner canthus of the eye and not directly over the nasiion.

The AEA continues its path along the anterior ethmoidal canal. In our series, this presented a mean length of 8.43±0.72 mm, similar to that published by Lang and Schäfer17 and Kainz and Stammberger.3 After passing through the anterior ethmoidal canal, which is wider at its exit from the orbit6 (with a diameter of about 1.2–1.3 mm16,17), the AEA enters the olfactory fossa through the vertical lamella of the cribriform plate, by the ethmoidal groove (Fig. 5A). This is the point of maximum fragility of the entire skull base.3 In 1988, Kainz and Stammberger3 showed that the bone thickness of the vertical lamella is 4 times less than the medial wall and up to 10 times less than the top of the ethmoid. This relationship of forces would explain the fragility of this point of the anterior skull base. In up to 45% of cases, the height of the vertical lamella can vary between both fossae,20 while it may be more horizontal, thus increasing the risk of damaging the artery, in about 50%.27 Consequently, working in an area lateral to the middle turbinate reduces the risk of bleeding from the AEA and of CSF fistula.3

The AEA ends its path entering into the anterior cranial fossa between the middle third and the anterior third of the olfactory fossa. Once there, it splits into several branches: anterior meningeal artery, anterior nasal artery, medial and lateral superior nasal branches, and even branches to the olfactory bulb.17 Once in the nasal cavity nasal, it anastomoses with the nasal branches of the sphenopalatine artery in Kiesselbach’s plexus (Fig. 5B and C).

### Posterior Ethmoidal Artery

Anatomical variations at the origin occur more frequently in the posterior ethmoidal artery.17 It may have its origin in the AEA and also in the middle meningeal but, according to our series, it is most frequently found in the ophthalmic artery. In 3 fossae of 14 in which the PEA could be studied, we found variants of normality and the artery originated from a common ethmoidal artery (Fig. 3B).

Shortly after the ophthalmic artery enters the orbit, the PEA emerges in its posterior third, usually above the superior
oblique muscle. On its intra-orbital course, we observe it follows a superior convex loop and ends up above the oblique muscle. This is reflected in Fig. 6.

There are no well-documented anatomical references to identify the PEA in CT studies. Despite studying cadavers perfused with radio-opaque material, we could identify it in only 14/40 nasal fossae. This result may reflect one of the limitations of our study, since the presence of the PEA has been described in a greater percentage, up to 70%, in anatomical dissections. Its small calibre, usually less than 1 mm, could explain our findings, given that we studied the vascular content and not the ethmoid bone canal itself, as was the case in other series.

After its intra-orbital path, the PEA continues towards the frontoethmoidal suture and enters through the posterior ethmoidal canal to cross the ethmoidal labyrinth a few millimetres from the anterior wall of the sphenoid sinus, in the sphenoethmoidal angle. Its path in the ethmoidal canal is slightly shorter and has a more horizontal orientation than that of the AEA, with an angle of entry into the skull base between 0° and 18°. We documented an angle of 7.11° ± 4.07° although it is true that this variable could only be measured in 9 of 40 nasal fossae. This wide range could be justified by the high number of losses in the sample (Fig. 6).

It is a vessel of smaller calibre with a less tortuous path, which is sometimes difficult to locate during surgery. In our study, it was located at a mean distance of 11.24 ± 2.14 mm from the AEA (Fig. 2A). Given its variability, it is not a reliable reference for location endoscopically, with the anterior wall of the sphenoid sinus being a more constant surgical reference.

Its surgical importance is based mainly on its proximity to the optic nerve. The short distance between the 2 structures is variable and can range from 4 to 16 mm. In our series, the range was narrower, with values of 7.26 ± 1.32 mm, in possible connection with a much smaller sample size than that studied by Cankal et al. The close relationship between the PEA and the optic nerve demands extreme care during approaches that require working in this territory.

In our study, we carried out a comparative analysis between the 2 fossae. Although there were asymmetries in some of the variables, the differences were not statistically significant for any of the parameters studied. However, both sides of the CT should always be considered independently, so as to reduce the risk of bleeding and to assess possible anatomical variations (Table 3).

The present study has a number of weak points. Although we did not carry out a regulated study of internal validation of the measurements, these measurements were repeated in several scans without evidence of notable differences.

Another of its limitations is based on the inability to reproduce the technique in living patients for its use in daily practice. It is clear that some of the anatomical measurements presented are difficult to assess preoperatively, such as the distance from nasion to AEA, the distance from nasal spine to AEA or the length, and angles of the arteries in the ethmoidal canals.

Figure 5  Coronal (A) and sagittal (B) MIP reconstructions. Distal path of the AEA in the anterior cranial fossa, path in epidural space, and cribiform plate. (C) Terminal branches of the AEA (first arrow), the PEA (second arrow), and nasopalatine artery (third arrow). AEA: anterior ethmoidal artery; PEA: posterior ethmoidal artery; MIP: maximum intensity projection.

Figure 6  Path of the PEA. (A) Coronal MIP reconstruction: origin of the PEA in the ophthalmic artery. (B) Axial MIP reconstruction: path in ethmoidal labyrinth section. PEA: posterior ethmoidal artery; MIP: maximum intensity projection.
Despite all this, we believe that this anatomical study represents an important contribution to the knowledge on ethmoidal artery anatomy, since it explicitly defines their vascular territory and it includes radiological anatomy images that allow the observation of details not possible in conventional CT images.

Conclusions

Most of our results coincided with those published previously in radiological and dissection studies. The preparation of specimens according to the Thiel’s technique helps to study vascular anatomy. It also allows evaluation of parameters that would be impossible to analyse by conventional CT studies or CT scans with contrast.

We found variants of normality in 12.5% of the fossae. The AEA was absent in 5% of cases and we observed a common ethmoidal artery from which both the AEA and the PEA emerged in 7.5% of the cases.

Conflict of Interest

The authors have no conflicts of interest to declare.

References