



# The Endoscopic Anatomy of the External Acoustic Meatus and of the Middle Ear in Dry Temporal Bones: A Study Conducted Using Digital and Mobile Device Technology

Fernando P. Gaspar-Sobrinho<sup>1</sup>  Aline L. S. Trzan<sup>1</sup>  Sandra de Q. Uzeda<sup>1</sup>  Joao Flavio Nogueira<sup>2</sup> 

<sup>1</sup> Department of Life Sciences, Universidade do Estado da Bahia, Salvador, BA, Brazil

<sup>2</sup> Health Sciences Center, Universidade Estadual do Ceará, Fortaleza, Brazil

Address for correspondence Fernando Pena Gaspar Sobrinho, PhD, Departamento de Ciências da Vida, UNEB, Avenida Silveira Martins, 2555 Salvador, Bahia 41150-000, Brazil (e-mail: fsobrinho@uneb.br).

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## Abstract

**Introduction** The endoscopic anatomy of the middle ear (ME) and of the external acoustic meatus (EAM) has been described in cadavers, in fresh temporal bones, or in vivo using conventional video recording, but not in dry bones or using an alternative inspection and recording technique.

**Objective** To study the anatomy of the ME and of the EAM in dry temporal bones using a smartphone-endoscope system.

**Methods** The EAM and the ME were studied in dry temporal bones using an endoscopic transcanal approach with a telescope connected to a smartphone (M-scope mobile endoscope app and adaptador, GBEF Telefonía, São Paulo, SP, Brazil).

**Results** Out of 50 specimens, 2 had exostosis of the EAM and 3 contained remains of the tympanic membrane. The anterior wall of the EAM was prominent in 10/48 specimens (20.8%). Ossicles were seen in 13/45 (28.8%), stapes at the oval window were seen in 12/45 (26.6%), and the incus was seen in 1/45 (2.2%) specimens. The facial canal was open and protruding in 15/45 (33.3%) and in 7/45 (15.5%) specimens, respectively. Of the 45 MEs evaluated, type A was predominant for finiculus (93.3%), subiculum (100%), and ponticulus (95.6%). The rest were type B. None was classified as type C. According to its position in relation to the round window, the fustis was classified into type A (68.9%) or B (31.1%). The pyramidal eminence, the bony portion of the Eustachian tube, the semicanal of the tensor tympani muscle, and the cochleariform process were visualized completely or partially in all cases.

**Conclusion** The use of a smartphone-based endoscopic transcanal procedure in dry temporal bones allowed the evaluation of anatomical variations in the EAM and in the ME.

## Keywords

- ▶ anatomy of the middle ear
- ▶ temporal bone
- ▶ endoscopic surgical procedure
- ▶ otologic surgical procedure
- ▶ external acoustic meatus

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## Introduction

The anatomy of the middle ear (ME) is complex and variable, and has implications in otologic surgical procedures. Transcanal endoscopic ear surgery has resulted in increased knowledge on the anatomy of the ear, particularly regarding areas that are less accessible under binocular microscopy.<sup>1</sup> Nevertheless, the endoscopic anatomy of areas of the ME such as the round window needs to be characterized in greater detail in view of the increasing interest in accessing the inner ear and the lateral base of the skull.<sup>2</sup>

Anatomical studies of the ear performed using transcanal endoscopy are generally conducted *in vivo*, on fresh cadavers, or in fresh temporal bones with the aid of a camera, monitor, and video recorder.<sup>3</sup> On the other hand, the teaching of anatomy usually begins with the bone structure and then proceeds to a description of the soft tissues. Pollak begins the endoscopic study of the ME with an image of a dry temporal bone.<sup>4</sup> Bone specimens are commonly found in human anatomy laboratories. They are easily handled and simply preserved when compared with the increasing difficulties involved in obtaining and preserving cadavers or fresh specimens.<sup>5</sup>

Smartphones have been used in several endoscopic procedures.<sup>6</sup> The development of digital mobile technology, together with software and an adaptor that connects the smartphone to an endoscope, forming an endoscopic mobile imaging system, has allowed diagnostic and therapeutic procedures to be performed in different fields of medicine. Use of digital and mobile device technology was first described in otorhinolaryngology in 2017.<sup>7</sup> The advantages of these systems include their portability, usability, multifunctionality and accessibility in relation to conventional video tower systems. Therefore, their use can complement and simplify studying, teaching and training in otology.

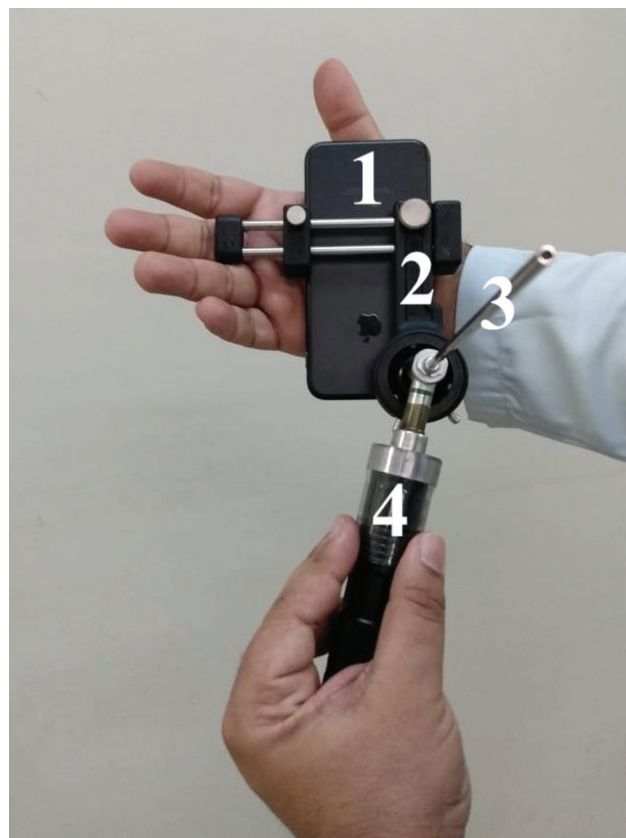
The objective of the present study was to describe anatomical variations in dry specimens of human temporal bones using a smartphone-based endoscope for transcanal surgery with the aid of digital and mobile device technology.

## Method

The internal review board of the institution approved the study protocol under reference CAAE 28952820.8.0000.0057. This was an experimental study conducted on human temporal bones using material from the collection belonging to the human anatomy laboratory at the Life Sciences Department, Universidade do Estado da Bahia.

A total of 50 dry specimens, divided equally between the right and left sides, were evaluated using a temporal bone dissection table. No distinction was made regarding age or gender. The specimens were placed in the anatomical position and submitted to smartphone-based transcanal endoscopy using digital mobile technology (M-scope, GBEF Telefonía, São Paulo, SP, Brazil), consisting of an adaptor and a camera app to integrate the endoscope with the smartphone (►Fig. 1).

The set of equipment used for the endoscopic procedures consisted of: 1) A Hopkins-type telescope of 4 mm in diame-

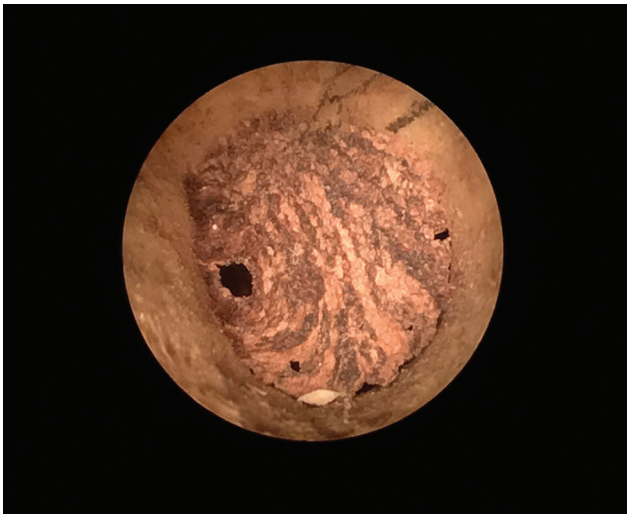


**Fig. 1** Set of equipment consisting of 1) a smartphone; 2) an adaptor; 3) a telescope and 4) a light source.

ter, 14 cm in length and with an angulation of 0° (Sopro-Comeg, Tuttlingen, Germany), with selected specifications in view of its multiple applications; 2) For convenience, instead of a handheld light source, an external light source was connected to the telescope using a fiber optic cable (►Fig. 1); 3) An iPhone 7 (Apple, Cupertino, CA, USA), on which the M-scope app was installed. Images were obtained by transcanal endoscopy at the porus acusticus externus and the tympanic sulcus.

The selection of the anatomical structures to be investigated was based on the relevance, accessibility and preservation of the bones evaluated. The following were analyzed: the bony portion of the external acoustic meatus (EAM), the ossicles, the promontory, the facial canal (tympanic segment above the oval window), the Eustachian tube, the pyramidal eminence, and the structures related to the round window, that is, the finculus, the subiculum, the ponticulus and the fustis. The latter was classified into types A and B as a function of the position of the axis in relation to the plane of the round window: inferior and perpendicular or superior and oblique, respectively. The other structures of the round window were classified as A (complete), B (incomplete) or C (absent).

No alteration was made to the anatomical specimens. In other words, no intervention was made to the anatomy of the temporal bone using drills or curettes to expose the middle or internal ear. Therefore, after transcanal endoscopy was performed and the images were obtained, the samples were



**Fig. 2** Left dry temporal bone: remains of tympanic membrane with a petrified appearance and perforations.

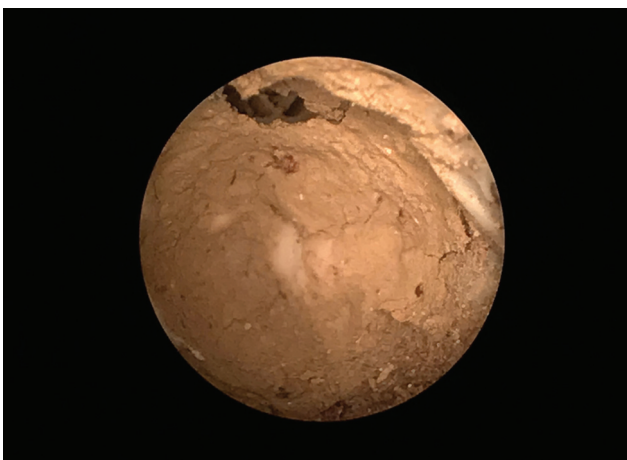
stored and returned intact to the collection of the anatomy laboratory.

**Results**

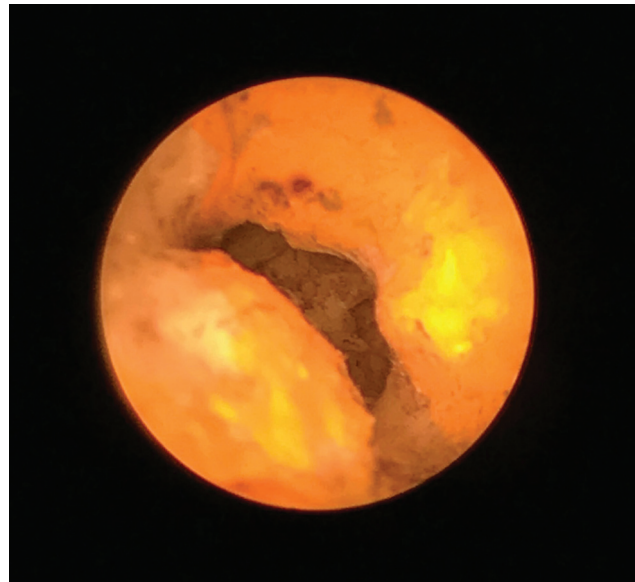
Out of the 50 temporal bones studied, 5 (10%; 3 left and 2 right) were excluded from the analysis of the ME. Three (6%) were excluded because the bones contained petrified (fossilized) tympanic membrane remains with perforation (►Fig. 2) or tympanic membrane atelectasis (►Fig. 3). The other 2 (4%) were excluded from the analysis due to the presence of exostosis of the external acoustic meatus (►Fig. 4). In all five cases, the blockage prevented the ME from being visualized during transcanal endoscopy, while the exostosis further prevented evaluation of the EAM. Consequently, the ME was evaluated in 45/50 of the temporal bones (90%), and the EAM in 48/50 specimens (96%).

The anterior wall of the EAM was prominent in 10/48 specimens (20.8%).

In the ME, the structures related to the round window niche are summarized in ►Table 1. Ossicles were found in



**Fig. 3** Left dry temporal bone: remains of tympanic membrane.



**Fig. 4** Left dry temporal bone: exostosis with blockage of the external acoustic meatus (anatomical specimen covered with yellow paint).

13/45 specimens (28.8%), with 12/45 (26.6%) consisting of stapes, all located in the oval window region (►Fig. 5). The remaining case (1/45; 2.2%) consisted of an incus, situated on the floor of the ME. An open and protruding facial canal was found in 15/45 (33.3%) and in 7/45 (15.5%) of the specimens, respectively. The pyramidal eminence, the bony portion of the Eustachian tube, the semicanal of the tensor tympani

**Table 1** Anatomical variations in structures related to the round window

	Type A		Type B		Type C	
Finculus	42/45	93.3%	3/45	6.7%	0	0.0%
Fustis	31/45	68.9%	14/45	31.1%	–	–
Subiculum	45/45	100%	0	0.0%	0	0.0%
Ponticulum	43/45	95.6%	2/45	4.4%	0	0.0%



**Fig. 5** Middle ear in a left dry temporal bone: 1) stapes; 2) subiculum; 3) fustis; 4) finculus; 5) promontory; 6) Eustachian tube; 7) semicanal of the tensor tympani muscle.

muscle, and the cochleariform process were visualized completely or partially in all temporal bones.

## Discussion

Dry bones were yet to be used in endoscopic studies of the ear anatomy. Most published papers involve the study of cadavers and deal individually with specific structures of the ME, such as the ponticulus,<sup>8</sup> the fustis,<sup>2</sup> the round window region,<sup>9</sup> and the oval window.<sup>10</sup> These studies generally used conventional monitors, cameras and recorders. Conversely, the present exploratory study evaluated the bony EAM and various structures in the ME in dry human temporal bones assessed using smartphone-based transcanal endoscopy.

The anatomical findings of the present study are in agreement with others already published in the literature. Sahin et al.<sup>1</sup> found a prominent anterior wall in the EAM in 26.4% of the specimens (27/204), compared with 20.8% of the specimens in the present study. A prominent anterior wall in the EAM hampers visualization of the tympanic membrane, both during routine otoscopy and during otologic surgery, and is particularly limiting in binocular microscopy. However, in endoscopy, this difficulty is overcome because this technique allows the tympanic membrane to be visualized from different angles. Otherwise, this blind spot can interfere with the clinical and surgical evaluation of the patient. In otologic surgery, meatoplasty may be necessary in cases of a prominent anterior wall in the EAM.

The present study allowed the structures related to the round window to be evaluated. The frequency of a type A finiculus was greater than that of type B (93.3 versus 6.7%), and no cases of type C were found. Marchioni et al.<sup>11</sup> reported an incidence of types A, B and C of 92.9% (39/42), 2.4% (1/42) and 4.8% (2/42), respectively. In agreement with the findings of these authors, in the present study a complete subiculum (type A) was detected in all the specimens examined. Sahin et al.<sup>1</sup> reported frequencies of 66.7% (136/204), 10.3% (21/204) and 23% (47/204), respectively, for subiculum types A, B and C. The finiculus and the subiculum form the lower and upper boundaries of the round window, respectively. In all cases, the presence of the complete structure (type A) favors its identification and anatomical reference. On the other hand, an incomplete structure (type B) may be associated with recesses and could mask diseases such as cholesteatoma.

The fustis was visualized in all the specimens evaluated. The incidence of type A fustis in the present study was greater than that of type B (68.9 versus 31.1%). Marchioni et al.<sup>11</sup> reported an incidence of type A of 71.4% (30/42) and an incidence of type B of 28.6% (12/42). There were no reports of type C in either study. The fustis is described as a bony structure linking the styloid process with the basal turn of the cochlea. It is an anatomical reference for accessing the round window and the subcochlear canaliculus. The latter is the route of surgical access to the petrous apex of the temporal bone, while the former is the site at which the cochlear implant electrode is inserted. In type A fustis, the axis is perpendicular to the plane of the round window, but it

is oblique in type B.<sup>11</sup> Consequently, this is a distinction with significant surgical implications.

In agreement with the results reported by Bonali et al.,<sup>12</sup> in the present study the ponticulus was identified in all the temporal bones. Holt<sup>8</sup> reported identifying the ponticulus in 80% of the specimens (40/50), Cheitã et al.<sup>13</sup> in 83.8% of the specimens (28/37), Marchioni et al.<sup>11</sup> in 89.5% (34/38) of the specimens, and Sahin et al.<sup>1</sup> in 88.7% of the specimens (181/204). In the present study, type A was more common than type B (95.6 versus 4.4%). In the literature, the incidence of type B has ranged from 8.1<sup>13</sup> to 27.2%.<sup>12</sup> The ponticulus is defined as a bony ridge linking the promontory to the pyramidal eminence. Depending on its morphology, the ponticulus may involve certain risks in that it may mask the matrix of a cholesteatoma, for example.

The facial canal, the pyramidal eminence, the promontory, the Eustachian tube, the semicanal of the tensor tympani muscle, and the cochleariform process were partially or completely visualized in all specimens. Of these, the integrity of the facial canal is of particular interest, since dehiscence or protrusion increases the risk of a facial nerve lesion. Sahin et al.<sup>1</sup> reported an incidence of dehiscence and of protrusion of the facial canal in 15.6% (32/204) and in 4.4% (9/204) of the specimens, respectively. In the present study, these frequencies were of 33.3 and 15.5%, respectively. In cholesteatoma, a prevalence of 54.8% was reported for dehiscence of the facial canal.<sup>14</sup>

Remains of tympanic membrane can be seen in dry temporal bones. In the present study, the prevalence of this finding was of 6%. The tympanic membranes had a petrified appearance, with evidence of atelectasis in two cases, suggesting the usefulness of transcanal endoscopy in forensic science. Otopathies may predispose to such findings. Although otoscopy is used in forensic autopsy practice,<sup>15</sup> we were unable to find any reports on petrified tympanic membranes. Nevertheless, studies conducted using otoscopy in paleontology have identified remains of tympanic membranes in mummies.<sup>16</sup> When examining cadavers, Sahin et al.<sup>1</sup> detected pathologies in the tympanic membrane in 6% of the specimens (12/102), but no pathology in the bony EAM such as the exostosis described here.

Dry temporal bones may contain ossicles. In the present study, ossicles were found in 28.8% of the specimens. Stapes were the most commonly found ossicle and were all situated within the oval window. Incus was found in only one case. Studies conducted on cadavers usually test the ossicular chain and dearticulate it. One study described the artificial anchoring of the stapes with cyanoacrylate in temporal bones for the purpose of surgical training in stapedotomy.<sup>17</sup> Although dry specimens lack articulation and soft tissues, the presence of ossicles can be useful for research and teaching purposes.

A 4-mm telescope was used in the present study; nonetheless, dissections of temporal bones or surgeries can be performed using a 2.7 or 3-mm telescope with angulations of 0, 30, 45 and 70 degrees.<sup>18,19</sup> Positive angulations allow hidden areas of the jugular, of the carotid, of the tegmental (tegmen tympani) and of the mastoid walls, not dealt with here, to be

visualized. Furthermore, in the conventional system, the use of monitors offers an amplified view, whereas the camera system supplies high-resolution images that are, however, comparable with those obtained using digital and mobile device technology.<sup>20</sup>

In the present study, digital and mobile device technology using an endoscope and smartphone allowed visualization and recording for the purpose of research in anatomy. Thanks to the multifunctionality of the smartphone and the compactness of the endoscope, digital and mobile device technology renders the equipment portable, versatile and accessible compared with conventional video towers with a monitor, camera and recorder.<sup>7,20</sup> Further studies with smartphone-based transcanal endoscopy should be conducted to examine specific structures of the temporal bone both in the context of anatomy and in other related fields of study.

## Conclusion

The present study enabled anatomical variations in the EAM and in the ME to be identified. It was possible to examine the bony portion of the EAM and areas of the ME such as the round window and the facial canal, both of which are of surgical importance. The results agree with previous reports in the literature. The absence of soft tissues limits studies conducted using dry bones; however, they allow detailed evaluation of the bone structures, since other tissues that could obscure them are absent. Moreover, bone specimens in general are easier to obtain, conserve, store and handle.

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