Acta Scientific Orthopaedics (ISSN: 2581-8635)

Volume 8 Issue 1 January 2025

Research Article

Middle Ear Exploration Protocol: Anatomical Foundations via Computed Tomography

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DOI: 10.31080/ASOR.2025.08.1014

Received: December 02, 2024

Published: December 31, 2024

Abstract

Computed tomography (CT) of the ear has become a highly requested study in recent years by audiology and otorhinolaryngology services. The aim of this work is to streamline and organize its exploration while presenting the anatomical foundations of the middle ear. The protocol and examination described here are those performed at our hospital, UMAE T21 HGZ, León, Guanajuato.

The anatomical foundations focus on studying the petrous portion of the temporal bone. The ear is composed of three sections, named from the most lateral to the most medial region of the temporal bone: the external ear, middle ear, and inner ear.

The middle ear has the shape of a geometric "cube" and serves to amplify sound from the tympanic membrane to the oval window through a series of interconnected ossicles that function as levers.

The evaluation approach proposed in this study is based on this geometric figure, assessing its shape, contents, and the structures that pass through it.

Keywords: CT Protocol; Middle Ear; Geometric Faces; Content; Traversing Structures

Abbreviations

mAs/kV: Milliampere-seconds/kilovolts; IMSS: Instituto Mexicano del Seguro Social; CT: Computed Tomography; UMAE T21 HGZ: Unidad Médica de Alta Especialidad T21 Hospital General de Zona

Introduction

The study of the middle ear through computed tomography (CT) is a valuable tool for diagnosing various pathologies. A basic understanding of anatomy is essential across multiple medical specialties. It is beneficial to examine this region in an organized and systematic manner [1]. The aim of this study is to facilitate and structure the exploration of the middle ear while providing the anatomical foundations for studying this region. The anatomy of the temporal bone is one of the most complex areas of the skull, and CT imaging aids significantly in achieving these objectives.

Computed tomography has enhanced the evaluation of the middle ear and its components, thanks to coronal, sagittal, curved, and double-oblique reconstructions. Layton., *et al*. reported in 2011 that small temporal bone structures could be confidently identified using images reconstructed in various planes [2].

Materials and Methods

For middle ear studies, the protocol involves setting the superior boundary at the roof of the frontal sinus and the inferior boundary at the mastoid apex, with slices parallel to the orbital plane (Figure 1A). The slice thickness is 0.8 mm, reconstructed at 0.4 mm, with 250/120 mAs/kV settings. Typically, the scan is performed without contrast, depending on the reason for the referral.

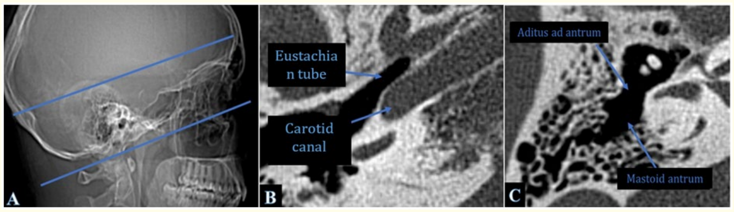

Figure 1: A) Lateral topogram of a CT scan, with blue lines indicating the protocol boundaries.

B) Axial plane showing the anterior face, with arrows pointing to the Eustachian tube and the carotid canal (CC).

C) Axial plane showing the posterior face, with arrows indicating the mastoid antrum and the aditus ad antrum.

Exploration method

Literature suggests following a systematic and organized approach to evaluate middle ear structures. This study proposes visualizing the middle ear as a polyhedral structure (cube), assessing its six faces, content, and traversing structures. This method helps ensure that no components are overlooked, reducing diagnostic errors.

Faces

Six faces are evaluated: the anterior (tubal), posterior (mastoid), superior (tegmental), inferior (jugular), lateral (tympanic), and medial (labyrinthine).

The anterior or tubal face requires an axial plane for its study. It is associated with the carotid canal, the Eustachian tube, and the tensor tympani muscle canal (Figure 1B).

The posterior or mastoid face, like the anterior face, is studied in the axial plane. According to the anatomical division (detailed later), its superior or epitympanic portion is related to the aditus ad antrum, the mastoid antrum, and the mastoid, which is an air-filled cavity divided into numerous compartments by septa (Figure 1C). The size and configuration of the mastoid air cells vary significantly [4].

The superior or tegmental face is best visualized in the coronal plane. It is associated with the roof of the tympanic cavity, known as the tegmen tympani, and the mastoid air cells (Figure 2A).

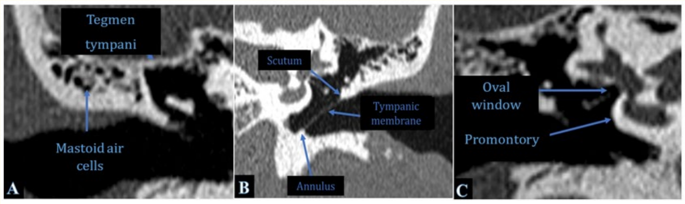

Figure 2: A) Coronal plane of the superior face, with arrows pointing to the tegmen tympani and the mastoid air cells.

B) Coronal plane of the lateral face, with arrows indicating the tympanic membrane and its insertions.

C) Coronal plane of the medial face, with arrows highlighting the oval window above the cochlear promontory.

The lateral or membranous face separates the external ear from the middle ear. Its evaluation requires both coronal and axial planes, as it is where the tympanic membrane inserts, necessitating proper window adjustment for optimal visualization. The tympanic membrane has a 45-degree angle and maximum dimensions of 10 mm in length, 9 mm in width, and a thickness of 0.05 to 0.09 mm. Histologically, it is

composed of three layers (external, intermediate, and internal) and has two portions

- **Pars flaccida (Shrapnell's membrane):** The smaller and thinner portion, located in the upper third.
- **Pars tensa:** The thicker portion, located in the lower two-thirds (Figure 2B).

The tympanic membrane inserts superiorly at the "scutum" and inferiorly at the "annulus" [4] (Figure 2B).

The medial or labyrinthine face is formed by the otic capsule, a dense bone that encloses the labyrinthine structures of the inner ear [5]. This face borders the inner ear and communicates with it through two openings: the oval window and the round window. A bony projection called the “promontory” aids in the visualization of both windows (Figure 2C), which are critical in diagnosing various conditions, such as otosclerosis and malformations [6].

The inferior or jugular face is best evaluated in the coronal plane. It is named for its relationship with the jugular bulb of the internal jugular vein. In some cases, air cells may be interposed between the middle ear cavity and the internal jugular vein (Figure 3A).

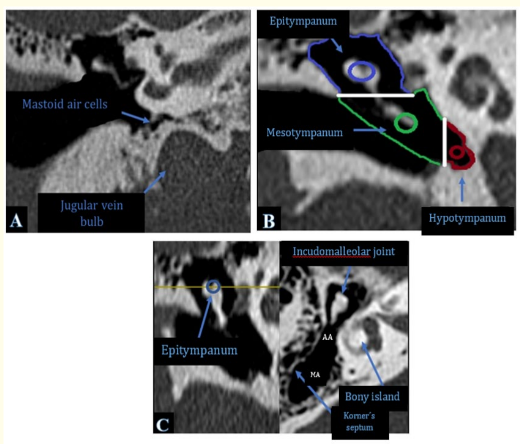

Figure 3:

A) Coronal plane showing the inferior or jugular face, with arrows pointing to the jugular bulb of the internal jugular vein and the mastoid air cells.

B) Coronal plane illustrating the anatomical division of the middle ear: epitympanum in blue, mesotympanum in green, and hypotympanum in red.

C) Coronal view on the left and axial view on the right at the level of the epitympanum, demonstrating the communication between the epitympanum and the mastoid (AA: aditus ad antrum)(MM: Mastoid antrum).

Content

For its study, a widely recognized anatomical division is used. To orient and define its boundaries, the coronal plane is essential. This division uses the insertion points of the tympanic membrane as references and is divided into three regions

The epitympanum is the most superior region, bounded by a line extending from the scutum to the tympanic portion of the facial nerve (Figure 2B). In this region, the following structures can be identified:

- Head of the malleus.
- Body and short process of the incus.

The head of the malleus articulates with the body of the incus, forming the incudomalleolar joint, which resembles an “ice cream cone” in axial planes [7]. The epitympanum communicates with the mastoid antrum via the aditus ad antrum, located medial to the bony island formed by the lateral semicircular canal. The mastoid antrum is separated from the mastoid air cells by Korner’s septum, as shown in figure 3C.

The mesotympanum is located adjacent to the tympanic membrane, between the epitympanum and the hypotympanum (Figure 2B). This region contains the incudostapedial joint, the origin and course of the tensor tympani muscle, the stapes, and the pyramidal eminence. Within the pyramidal eminence, there are two circular zones with soft-tissue density: the more lateral corresponds to the facial nerve, and the medial zone corresponds to the stapedius muscle (Figure 4B).

The hypotympanum is the lowest of the three regions, bounded by a line extending from the annulus to the cochlear promontory. It is an air-filled cavity that, due to its dependent position, can become occupied by secretions (Figures 2B and 4C).

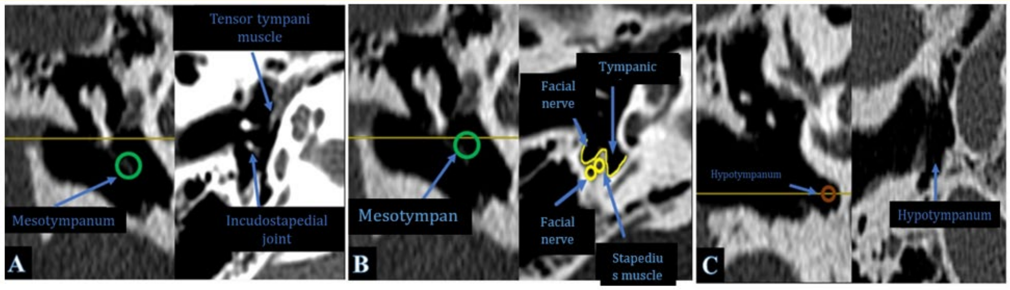

Figure 4: A) On the left, coronal plane showing the mesotympanum highlighted in a green circle, with the yellow line indicating the axial plane level. On the right, axial plane with arrows pointing to the tensor tympani muscle and the incudostapedial joint.

B) On the left, coronal plane indicating the level of the cut. On the right, the pyramidal eminence is highlighted in yellow.

C) On the left, coronal plane showing the level of the cut. On the right, axial plane at the level of the hypotympanum

Prussak's Space is a small recess located in the middle ear. Its boundaries are:

- **Lateral:** The pars flaccida (Shrapnell's membrane).
- **Superior:** The scutum.
- **Inferior:** The lateral process of the malleus.
- **Medial:** The neck of the malleus (Figure 5A).

Ossicular chain

The ossicular chain transmits and amplifies vibrations from the tympanic membrane through the middle ear cavity, leading to movement of the oval window, which is connected to the stapes [3,16,17].

This chain consists of three ossicles named for their morphological appearance: the malleus, incus, and stapes (Figures 4A, 4B, and 5B). They are connected by synovial joints. The joint between the head of the malleus and the body of the incus is called the incudomalleolar joint, which has the appearance of an "ice cream cone" (Figure 3C). The joint between the lenticular process of the incus and the head of the stapes is called the incudostapedial joint (Figure 4A).

The ossicular chain amplifies vibrations from the tympanic membrane. According to Helmholtz (1868), "The tympanic membrane is 20 times larger than the oval window," which contributes to this amplification.

Four suspensory ligaments stabilize the ossicles: the superior malleal, lateral malleal, posterior malleal, and posterior incudal ligaments. These ligaments can sometimes be visualized on CT as thin linear structures, with the lateral malleal ligament being the most commonly identifiable [8].

Malleus

The malleus rests on the tympanic membrane, making its location easy to identify. It consists of

- **Head:** Articulates with the body of the incus.
- **Neck:** Serves as the insertion point for the tensor tympani muscle.
- **Manubrium:** Anchors to the tympanic membrane.
- **Anterior and lateral processes:** These are attachment points for the anterior and lateral malleal ligaments, which provide support to the malleus.

Incus

The incus has a shape resembling a premolar tooth, with two widely divergent processes of different lengths [9]. It articulates with both the malleus and the stapes and consists of

- **Body:** Articulates with the head of the malleus.
- **Short process:** Provides support by attaching to the posterior wall of the middle ear.
- **Long process with the lenticular process:** Articulates with the head of the stapes.

Stapes

The stapes is the smallest of the three ossicles and consists of

- **Head:** Articulates with the lenticular process of the incus.
- **Neck:** Serves as the insertion point for the stapedius muscle.
- **Anterior and posterior crura:** Provide structural support.
- **Base (footplate):** Anchored to the oval window by the annular ligament [10] (Figure 5C).

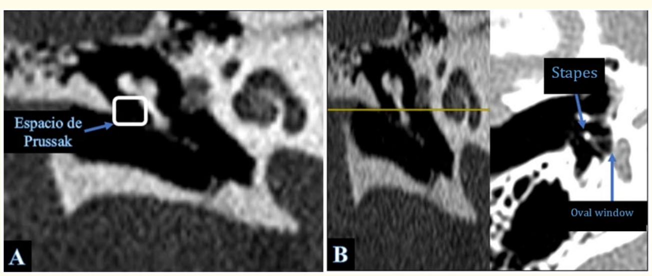

Figure 5:

A) Coronal plane showing a white square delimiting Prussak's space.

B) On the left, a coronal image with a yellow line indicating the level of the axial cut shown on the right. On the right, the stapes and the oval window are visualized.

Tensor tympani muscle

The tensor tympani muscle originates above the bony portion of the Eustachian tube and travels posteriorly, forming a distinct curve around the cochleariform process. It inserts into the neck of the malleus (Figure 4A).

Stapedius muscle

The stapedius muscle is housed in its own canal and consists of two portions. The first portion is located in the posterior wall, anterior to the third segment of the facial nerve. The second portion, visible on CT, is situated within the pyramidal eminence, from which the muscle tendon emerges to insert into the neck of the stapes. Upon contraction, it moves the stapes posteriorly (Figure 4B).

Passing structures: Facial nerve (VII Cranial nerve)

The facial nerve can be best visualized using axial, coronal, and curved reconstructions. It has three segments that traverse the ear: intracanalicular, labyrinthine, and tympanic (Figure 6A and B).

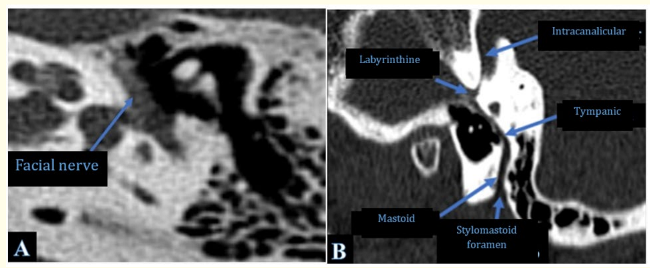

Figure 6:

A) Axial plane of the tympanic portion of the facial nerve.

B) Curved reconstruction of the facial nerve.

Due to the narrow canal through which it passes, the facial nerve is particularly vulnerable to trauma. Facial nerve paralysis occurs in 7% to 50% of temporal bone fractures [11,12]. The perigeniculate portion of the facial nerve is the most susceptible due to its anatomical position [8,13].

The facial nerve originates from the brainstem as two roots: motor and sensory. The motor root is the larger of the two. Upon exiting the medulla oblongata, the nerve passes through the pia mater, which provides it with a sheath. It then moves forward and outward from the posterior fossa, entering the internal auditory canal in the anterosuperior quadrant alongside the intermediate nerve (Wrisberg's nerve) and the internal auditory artery.

Intracanalicular segment

This segment of the facial nerve measures 7 to 8 mm in length and runs superior to the cochlear nerve and the falciform crest, as shown in the image [14].

Labyrinthine segment

This portion is approximately 3 to 4 mm long and travels forward and outward within its bony canal, the Fallopian canal. It curves above the cochlea and anterior to the semicircular canals. At the end of this canal lies the geniculate ganglion, the true origin of its sensory component. The geniculate ganglion is located at the first bend of the Fallopian canal, also known as the facial nerve's first genu. At this point, the nerve turns posteriorly, forming the "first genu," located above the cochlear base (over the promontory near the cochleariform process) [15].

Tympanic segment

The tympanic segment begins at the distal end of the geniculate ganglion, marking its most anterior boundary. It measures 12 mm in length and runs posteriorly and outward along the major axis of the petrous bone, following the medial wall of the tympanic cavity. It travels above the oval window and below the lateral semicircular canal. At the level of the tympanic sinus, the nerve changes direction at the second genu, adopting a vertical course. It passes through the anterior mastoid region and exits the skull base via the stylomastoid foramen. The mastoid segment measures 15 to 20 mm in length.

Facial nerve branches in the ear

The facial nerve has three main branches in its course through the ear. One of these is the greater superficial petrosal nerve, which departs at the geniculate ganglion and exits the petrous bone through the facial canal, as illustrated in the image.

Results and Discussion

The Middle Ear Exploration Protocol via Computed Tomography (CT) presents a structured and innovative approach to studying an anatomically complex region, addressing the clinical demand for detailed imaging in otology and audiology. This discussion explores the protocol's methodology, clinical applications, and its contribution to diagnostic accuracy, integrating references to support key points.

Significance of CT in otology

CT imaging has revolutionized the evaluation of temporal bone structures due to its ability to provide high-resolution, cross-sectional images. It has been well-documented as the gold standard for diagnosing bony abnormalities of the middle and inner ear [1,9,15]. Layton., *et al*. [2] emphasized that the coronal, sagittal, and oblique reconstructions allow the precise identification of fine anatomical details, such as ossicles and the facial nerve.

The protocol proposed here aligns with these advancements, incorporating imaging parameters optimized for temporal bone evaluation, including a thin slice thickness of 0.8 mm, reconstructed to 0.4 mm. Such settings ensure clarity in visualizing critical structures, including the ossicular chain and the oval and round windows, as shown by Fatterpekar., *et al*. [9] in their study on 3D CT imaging of the temporal bone.

Geometric approach to the middle ear

A standout feature of this protocol is the use of a geometric "cube" model for organizing the study of the middle ear. This conceptualization simplifies anatomical complexity by breaking the evaluation into six distinct faces

- **Anterior (tubal):** Includes structures like the Eustachian tube and carotid canal, critical for understanding conditions such as patulous Eustachian tube syndrome [6].
- **Posterior (mastoid):** Related to the mastoid antrum and air cells, vital for assessing mastoiditis or cholesteatoma [4,6].
- **Superior (tegmental):** Corresponds to the tegmen tympani, a region implicated in cerebrospinal fluid leaks [9].
- **Inferior (jugular):** Provides insights into the relationship with the jugular bulb, relevant for diagnosing jugular bulb anomalies [15].
- **Lateral (tympanic):** Delineates the tympanic membrane and its insertions, essential for evaluating tympanic membrane perforations [5].
- **Medial (labyrinthine):** Offers a view of the oval and round windows, critical in diagnosing otosclerosis and other conductive hearing loss causes [3].

The systematic evaluation of these faces ensures a comprehensive approach, minimizing the likelihood of diagnostic errors.

Detailed analysis of middle ear contents

Dividing the middle ear into epitympanum, mesotympanum, and hypotympanum enhances diagnostic precision

- **Epitympanum:** Houses structures like the head of the malleus and the incudomalleolar joint. Virapongse., *et al.* [4] highlighted the importance of evaluating this region in congenital anomalies and inflammatory conditions.
- **Mesotympanum:** Contains the tensor tympani muscle and incudostapedial joint, areas prone to pathology in trauma and otosclerosis [3,6].
- **Hypotympanum:** Often occupied by fluid in inflammatory or infectious conditions, as demonstrated in studies by Mayer., *et al*. [5].

Furthermore, the identification of Prussak's space—a key site for cholesteatoma development-is particularly valuable, as Zeifer., *et al*. [6] noted its role in diagnosing congenital and acquired middle ear pathologies.

Advanced imaging and reconstructions

The application of curved and double-oblique reconstructions significantly enhances the evaluation of intricate structures. For instance, the facial nerve's labyrinthine and tympanic segments, described by Juliano., *et al*. [1], are better visualized with these advanced techniques. Studies have shown that precise visualization of these segments is critical in diagnosing temporal bone fractures and assessing facial nerve paralysis [11,12].

Clinical implications and standardization

The protocol's systematic methodology not only improves diagnostic accuracy but also supports consistent interobserver evaluations. As Fatterpekar., *et al*. [9] suggested, standardizing imaging parameters across institutions ensures reliability and repeatability in diagnostic practices. Sharing such protocols fosters collaborative learning and optimizes patient outcomes, a sentiment echoed by Lambert and Brackmann [13] in their analysis of facial paralysis in temporal bone fractures.

Conclusion

This protocol enhances middle ear evaluation by integrating a geometric approach, precise anatomical delineation, and advanced imaging techniques. Its contributions include improved diagnostic accuracy, reduced observer variability, and the facilitation of interinstitutional standardization. By leveraging evidence-based methodologies and fostering collaboration, the protocol supports better patient care and advances in otologic imaging.

Acknowledgements

We would like to acknowledge our former professors at UMAE T1 in the radiology department, especially Doctor Sandra Bolaños Hurtado.

Conflict of Interest

Not applicable.

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