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OTOLOGY

Pars tensa and tympanicomalleal joint: proposal for a new anatomic classification

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Abstract

Purpose The tympanic membrane (TM) belongs to the ear. Despite its place in the ear anatomy, can we give it also a different anatomic classification? The main objective is to clarify the nature of TM, tympanic bone and malleus to propose a new anatomic classification.

Methods This cadaveric study was performed in two human heads and six fresh temporal bones. A study of the temporomandibular joint, external acoustic meatus (EAM), TM and middle ear structures was conducted. A medical literature review englobing anatomy, embryology, histology and phylogeny of the ear was performed and the results were compared with the results of the dissection.

Results The external ear is constituted by the auricle and the EAM. This last segment is made by a cartilaginous and an osseous portion. The osseous portion of the EAM is constituted mainly by tympanic bone. The external ear is separated from the middle ear by the TM. Inside the middle ear, there are three ossicles: malleus, incus and stapes, which allow the conduction of sound to the cochlea. Based on the anatomic dissection and medical literature review of the tympanic bone, malleus and TM, we propose that these structures are interconnected like a joint, and named it "Tympanicomalleal joint".

Conclusions It seems that the TM can be part of a joint that evolved to improve sound transmission and middle ear protection. Thinking TM has part of a joint may help in the development of more efficient reconstructive surgical techniques.

Keywords Anatomy · External ear · Middle ear · Ear ossicles · Tympanic membrane · Tympanoplasty

Introduction

The tympanic membrane (TM) is part of the lateral wall of the middle ear, separating the external ear from the middle ear. The TM is divided into two parts, the *pars flaccida* and *pars tensa*, which have different functions and histologies. Some authors debate the reason for the TM [1, 2]; however, only a few studies have investigated its true nature. For example, why is the *pars tensa* inserted into the tympanic part of the temporal bone and supported by an organized fibrocartilaginous ring? The TM forms part of the ear, but can we be more specific and improve the classification?

To clarify these issues, we considered anatomic, embryologic, phylogenic, and histologic data from the external and middle ear to determine whether the TM could simultaneously belong to another anatomic system.

The aim of this study was to better classify the TM, detailing the anatomy of the *pars tensa* and its relation to neighboring structures. Furthermore, we explored the possible application of this knowledge to daily clinical practice and reconstructive surgery.

Materials and methods

The study examined tissues from human cadavers and fresh frozen temporal bones, as well as published medical literature from the anatomic, embryologic, phylogenetic, and histologic perspectives of the external and middle ear.

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Source of cadavers and embalming technique

The cadavers used in this study were from individuals who donated their bodies for medical education and research, in accordance with the Ethical Research Committee. Donors provided premortem written consent for these uses.

We studied two human adult cadaveric heads embalmed through intermittent perfusion of an embalming solution comprised of aliphatic alcohols, diethylene glycol, and monoethylene glycol and kept at 4 °C [3]. We also studied six fresh (frozen) temporal bones harvested during autopsies, according to national law.

Temporal region dissection

The temporomandibular joint, external acoustic meatus (EAM), TM, and middle ear structures were dissected under a microscope. The structures and aspects detailed in this study are listed in Table 1.

Medical literature review

A search of English-language literature was performed using electronic and manual strategies. The electronic search was performed in the PubMed, ClinicalKey, and Google Scholar databases, using the following search terms: tympanic membrane anatomy, tympanic membrane physiology, tympanic membrane embryology, tympanic membrane histology, *pars tensa*, *pars flaccida*, external ear anatomy, and middle ear anatomy. No time limits were placed on the searches. The results of the literature review were compared with the dissection results (Table 2).

Table 1 Structures included in the dissection

External ear
Tympanic part of temporal bone
Tympanic membrane
Malleus
Other structures of the middle ear

Results

Anatomy of the external and middle ear

The ear is divided into three parts: external, middle, and inner. The external ear is the most lateral part and has two portions: the auricle and the EAM. The EAM extends from the concha to the TM [4, 5] (detailed in Fig. 1). Its lateral segment is composed of fibrocartilage and the medial part is bone [4]. The tympanic portion of the temporal bone forms the anterior, inferior, and most of the posterior part of the osseous portion. The remaining osseous segment is formed by the squamous portion of the temporal bone [5].

The external ear is separated from the middle ear by the TM. The middle ear cleft is composed of mastoid cells, the tympanic cavity, and the Eustachian tube. The tympanic cavity contains three auditory ossicles (the malleus, incus, and

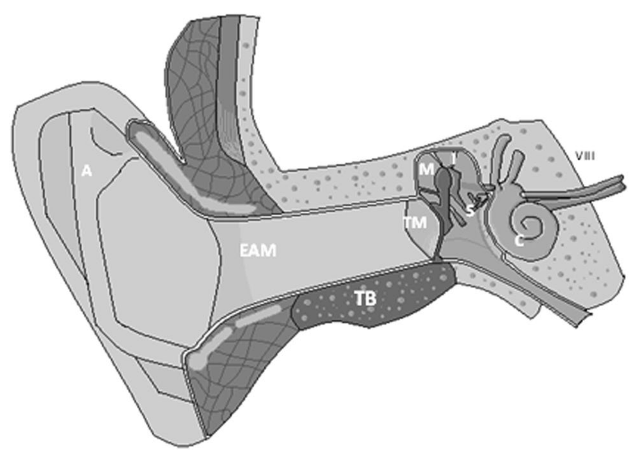

Fig. 1 Resumed ear anatomy. Highlighted in dark gray are the components of tympanicomalleal joint. *A* auricle, *EAM* external acoustic meatus, *TB* tympanic bone, *TM* tympanic membrane, *M* malleus, *I* incus, *S* stapes, *C* cochlea, *VIII* vestibulocochlear nerve. The image is not on real scale

Table 2 Literature review and anatomical dissection

Literature review	Anatomical dissection
Anatomical aspects (osteology, arthrology, vascularization and innervation)	External ear
	Tympanic part of temporal bone
	Tympanic membrane
	Malleus
	Other structures of the middle ear
Embryologic and phylogenic aspects (development and comparative anatomy)	External and middle ear
Histological aspects (including TM healing)	External and middle ear

stapes), which have important roles in the conduction of sound from the TM to the cochlea.

The medial most component of the ear is the inner ear, which will not be discussed in this work.

Next, we will detail the anatomical structures relevant to this study: the tympanic bone, malleus, and TM.

Tympanic part of the temporal bone

The tympanic portion of the temporal bone (or tympanic bone) is an incomplete tubular structure [5] below the squamous portion of the temporal bone and anterior to the mastoid process. It fuses medially with the petrous portion of the temporal bone, superiorly with the squamous part of the temporal bone, and posteriorly with the mastoid process. The fusion sutures are the squamotympanic and tympanomastoid fissures. The concave surface of the tympanic bone forms most of the osseous portion of the EAM. It has a narrow depression on its medial limit, the tympanic sulcus, where the TM attaches through a fibrocartilaginous ring termed the anulus. The malleal fold inserts into the anterior and posterior tympanic spines of the tympanic bone [6]. The external surface of the anterior wall of the tympanic bone is the posterior wall of the mandibular fossa, and the sharp, inferior wall of the tympanic bone is rooted in the sheath of the styloid process, named the vaginal process [5].

The tympanic bone, mandible, and most of the facial bones originate from the viscerocranium [7]. Comparative anatomy studies support the hypothesis that the malleus and tympanic bones both arise from the lower jaw [2, 8].

Tympanic membrane

The TM separates the external and middle ear; it has a conical shape [9] and is thin and semi-transparent [5]. It is surrounded by the tympanic anulus, which is inserted into the tympanic sulcus of the tympanic bone. The anulus and tympanic bone are absent in the superior segment of the TM [5]. The small triangular area of the TM located above the anterior and posterior malleal folds is the *pars flaccida*. It is relaxed because it has an external layer (epidermal) and an internal layer (mucosal), with a middle layer formed of loose collagen fibers [5].

Below the *pars flaccida* is the larger portion of the TM, the *pars tensa*. It is stiffer than the *pars flaccida* because its middle layer contains a fibrous stratum [5]. The fibers have different orientations (e.g., radial, circular, parabolic, and transversal) [6]; however, the most developed ones are the radial and circular collagen fibers. Radial collagen fibers connect the *manubrium*, spatula, and lateral process of the malleus to the anulus, whereas circular collagen fibers are mainly near the annulus. The inner surface of the TM is convex, and the point of greatest convexity is the umbo [5].

Some authors hypothesize that the *pars flaccida* has a minor role in sound conduction, but its most important function is to buffer against negative pressure from the middle ear cleft [10].

Malleus

The malleus is the more lateral ossicle. It is divided into the head, neck, and handle (or *manubrium*), has an anterior and a lateral process [5], and is covered by mucosa. The head is the ossicle's upper portion and is located in the epitympanic recess, where it articulates with the incus. The neck is the narrow segment between the head and handle [5].

The handle is connected to the TM and has an inferior, medial, and posterior orientation. Its inferior end is flattened transversely (the spatula) where the radial fibers of the TM insert into the malleus [6]. The tendon of the tensor tympani muscle attaches near the upper end of its medial surface. The anterior process is connected to the petrotympanic fissure by ligamentous fibers [5].

The lateral process of the malleus has a lateral orientation [5] and contacts the upper TM [5, 6]. The superior edge of the fibrous layer (*pars tensa*) relates to the posterior and anterior malleal folds. The posterior malleal fold is composed of mucosa and fibers [6]. The anterior ligament of the malleus and anterior tympanic spine are inside the anterior malleal fold [6] (Fig. 2).

The cartilaginous precursor of the malleus arises from the dorsal end of Meckel's cartilage. The malleus ossifies from a single endochondral center, with the exception of its anterior process that separately ossifies from dense connective tissue [5] and originates from the viscerocranium [11].

External and middle ear embryologic origins

In the 4th week of fetal development, several branchial arches develop from either side of the head. These are separated by external branchial grooves. The first groove invaginates and becomes part of the primitive EAM, oriented by the tympanic ring [12]. Some authors suggest that the EAM is induced as a lower jaw component [1].

A corresponding evagination comes from the pharynx, more specifically the first pharyngeal pouch, which grows outward and upward to eventually form the Eustachian tube. The mesoderm grows between the epithelium of the first branchial groove and the endoderm of the first pharyngeal pouch, separating these layers. The future TM is formed by all three of these germinal layers [13].

Blood supply

The arterial vascularization of the external and middle ear is rich in anastomoses. The main arterial blood supply of the

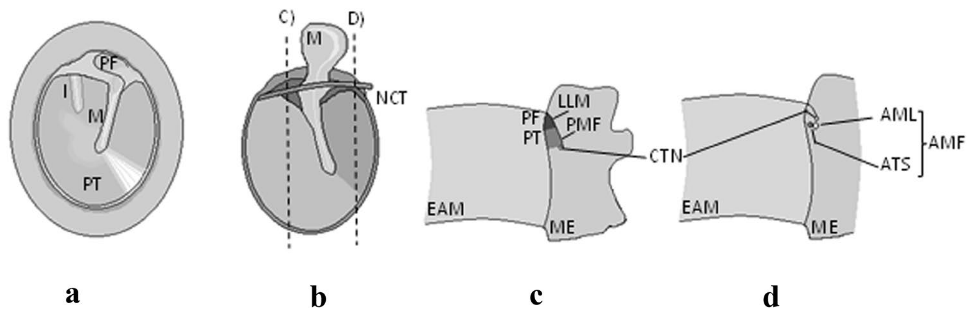

Fig. 2 Tympanic membrane of the right ear. **a** Lateral view; **b** medial view, **c** coronal cut of PMF, **d** coronal cut of AMF. *AMF* anterior malleal fold, *AML* anterior malleal ligament, *ATS* anterior tympanic spine, *CTN* chorda tympani nerve, *EAM* external acoustic meatus, *I* incus, *LLM* lateral ligament of the malleus, *ME* middle ear, *M* malleus, *PF pars flaccida*, *PMF* posterior malleal fold, *PT pars tensa*. The images are not on real scale. Based in Paço 2003 [6] and Drake et al. 2014 [16]

malleus is the anterior tympanic artery [14]. The TM is supplied by the deep auricular artery [17] and anterior tympanic artery [15]. The EAM is supplied by the posterior auricular artery, deep auricular artery [5], and auricular branches of the superficial temporal artery [5]. Venous drainage converges into the external jugular vein, maxillary veins, and pterygoid plexus [5].

Innervation

Sensory innervation of the EAM and the external layer of the TM is largely supplied by cranial nerves. Major sensory inputs travel through branches of the auriculotemporal nerve, a branch of the mandibular nerve (anterior and superior walls), and through the auricular branch of the vagus nerve (posterior and inferior walls). Minor sensory inputs travel through a branch of the facial nerve to the auricular branch of the vagus nerve [16]. The inner layer of the TM is innervated by the glossopharyngeal nerve [19].

Proposal for a new anatomic classification

Based on the anatomy, embryology and phylogenetic development of the tympanic bone, malleus and TM that was described above, we propose that these three structures are interconnected in a way similar to a joint.

Name of the proposed joint Tympanicomalleal joint.

Tympanicomalleal joint classification Semi-mobile syndesmosis.

Articular surfaces Malleus (*manubrium*, lateral process and spatula) and the tympanic part of the temporal bone (tympanic sulcus).

Ligaments Anterior and posterior malleal folds, *pars tensa* and tympanic anulus.

Articulation movements Passive adduction or abduction due to sound conduction and/or changes in middle ear cleft pressure.

Active adduction by contraction of tensor tympani muscle.

Discussion

The following section explains each joint characteristic to clarify our hypothesis (major joint features reviewed in Table 3). We first needed to clarify the term joint. A joint is the region where two or more bones are connected by a ligamentary system [17].

Tympanicomalleal joint classification

Since we inferred a connection between the tympanic part of the temporal bone and the malleus, we propose the designation of a tympanicomalleal joint. Anatomically, it would be classified as a fibrous joint, more precisely as a syndesmosis, because a fibrotic membrane connects both bones (detailed below).

Articular surfaces

The intervenient bones of this joint are the tympanic bone and malleus. The fibrous layer of the TM inserts into the *manubrium* and the lateral process (malleus articular surfaces) on one side, while the other inserts into the tympanic sulcus (tympanic bone articular surface) through a thick ligament called the anulus.

Two lines of evidence support this proposal.

1. The malleus and tympanic bones seem to have a direct connection in early mammal-like fossils (synapsids) and are both part of the mandible in those animals (Fig. 3). Recent genetic studies suggest that these structures have a close relationship during ear development. The EAM depends on tympanic ring development, and the malleus *manubrium* depends on external ear development.

Table 3 Resumed tympanicomalleal joint morphological features

Classification	
	Semi-mobile syndesmosis
Articular surfaces	
Malleus	Manubrium, spatula and lateral process
Tympanic bone	Tympanic sulcus
Ligaments	Anterior and posterior folds, *pars tensa* and tympanic anulus
Movements (adduction/abduction)	
Passive	Tympanic vibration due to sound conduction Changes in middle ear pressure
Active	Contraction of tensor tympani muscle
Healing	Acute healing phase with type I and III collagen production
Blood supply	*Arterial* Anterior tympanic artery, deep auricular artery, posterior auricular artery and auricular branches of superficial temporal artery *Venous* Veins that drain to external jugular veins, maxillary veins and pterygoid plexus
Innervation	Auriculotemporal nerve (mandibular nerve), auricular branch of vagus nerve, glossopharyngeal nerve

This kind of coordination is essential for normal TM formation [18]. If these bones are directly connected in early synapsids, is there an anatomic possibility that a bone can be replaced by ligament or fibrous tissue? After researching the literature, we identified a bone system that suffered evolutionary atrophy in humans: the hyoid apparatus. It is present in some mammals (e.g., dogs), but appears to have been lost during human evolution and replaced by the stylohyoid ligament. Evidence from some clinical cases has shown complete ossification of the hyoid apparatus [19] in a manner similar to the hyoid apparatus of other mammals. A similar situation could explain the existence of a fibrous membrane (the TM) connecting the tympanic bone with the malleus instead of bone.

2. After studying clinical cases with major EAM malformations, such as atresia, these changes appear to be correlated with the absence of a malleus *manubrium* [21, 22]. We found no description of a normal TM in any of these cases.

Ligaments

The main ligament is the fibrous layer of the TM (mainly *pars tensa*) and contains numerous collagen fibers (mostly type II) [15] displayed in a radial and circular organization. This fibrous layer of the *pars tensa* is reinforced by the anterior and posterior malleal folds, which also help to sustain the malleus and TM.

Joint movements

This joint is capable of some movement that we classified as passive and active. Passive movements include adduction and/or abduction in response to changes in middle ear cleft pressure and during its vibration due to sound conduction. Active adduction involves contraction of the tensor tympani muscle.

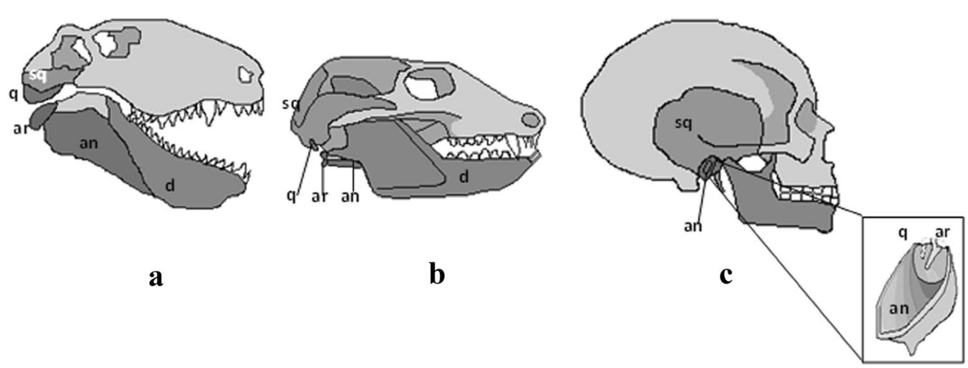

Fig. 3 Middle ear and temporomandibular joint evolution. Transition based in quadrate–articular (incus–malleus) to a temporo-dentary (mandible) joint. *sq* squamosal, *q* quadrate, *ar* articular, *an* angular, *d* dentary. The quadrate is homologous of incus, articular of malleus, angular of tympanic bone and dentary of mandible. **a** Dimetrodon skull; **b** Probainognathus skull; **c** *Homo sapiens* skull. The images are not on real scale. Based in Takechi and Kuratani 2010 [2], Carroll 1988 [20] and images of specimens

Other considerations

There are other factors that may support this new classification of the TM, namely

- *Histology* TM collagen fibers of the TM are mainly type II, which provides stiffness and assists in the transmitting sound to the inner ear [23].
- The outer layer of the TM is primarily innervated by the auriculotemporal nerve (branch of the mandibular nerve), as with other mandibular regions.

Tympanicomalleal pathologies

Pathologies of the tympanicomalleal joint are characterized by conductive hearing loss, as occurs when other ossicle joints are compromised. Since these joint components belong to the EAM and middle ear, they can be affected by pathologies that disturb this area. Common examples are chronic and acute external and middle otitis, tumors, and trauma.

From a functional perspective, the degree of conductive hearing loss will depend on the tympanicomalleal joint component affected. If the pathology occludes the EAM, as in obliterated exostosis, it will lead to an air–bone gap (ABG) of approximately 22 dB [24] (range of 10 [25] to 35 dB [26]).

Furthermore, if the TM is affected, for example, by a perforation, the mean ABG would be approximately 20 dB [27] (range of 5 [28] to 50 dB [29]).

Another specific TM pathology is myringosclerosis, which is characterized by calcareous deposits [29]. Extensive calcification of the TM can impair its function in a manner similar to ankylosis. Based on our experience, myringosclerosis that encompasses the TM and malleal folds can lead to a conductive hearing loss of 15–35 dB. If the myringosclerosis only involves the TM, the mean values of ABG can range from 1 [30] to 22 dB [31], depending on myringosclerosis plaque size.

A malleus fixation can lead to an ABG of 15–30 dB [32], and malleus fracture is related to an ABG of 15–60 dB [33].

Table 4 Examples of tympanicomalleal pathologies and their respective air–bone gap

Component	Pathology	Air–bone gap (range) (dB)
Tympanic bone	EAM obstruction, exostosis	10–35
Tympanic membrane	Perforation	5–50
	Myringosclerosis	1–35
Malleus	Fixation	15–30
	Fracture	15–60
Tympanomalleal joint/ external acoustic meatus	Atresia	40–60

Pathologies where the tympanicomalleal joint does not develop properly, such as EAM atresia, can lead to an ABG of 40–60 dB [34, 35]. These pathologies are described in Table 4.

Tympanicomalleal joint concept and reconstructive surgery of the TM

Surgical repair of the TM using a skin graft was first described in 1878 by Berthold [36], but its main principles were only standardized in 1952 by Wullstein who described the type I tympanoplasty [38]. Since its first description, this surgery has undergone a long process of improvement. In recent years, several materials (autologous grafts made of skin, fascia, vein, dura mater, cartilage, perichondrium, subcutaneous tissue, and periosteum [37]) have been used to reconstruct the TM. The current success rate with temporal fascia or cartilage grafts is approximately 90% [38].

We will now discuss tympanoplasty from a global perspective with the tympanicomalleal joint concept in mind.

Articular surfaces

In type I tympanoplasty, the TM is reconstructed and is in contact with the malleus. This establishes a connection between the articular surfaces of the tympanicomalleal syndesmosis, namely the malleus *manubrium* (and spatula) and tympanic bone.

Ligaments and articular movements

When possible, it is important to preserve the articular ligaments to preserve joint movement, in particular the ligaments that sustain the malleus.

Reconstruction of the *pars tensa* should use a similar material, especially regarding stiffness and sound conduction. Cartilage and temporal fascia are two of the most useful grafting materials. Temporal fascia is made up of type I collagen, while cartilage (e.g., tragal cartilage) contains type II. The decision to use a graft material depends on clinical aspects, such as the pathology that initially caused the TM perforation. As an example, cartilage is more suitable for patients with Eustachian tube dysfunction [39] and seems to deliver better closure results [39, 40]. If the cartilage thickness is < 0.5 mm, it possesses similar acoustic properties to the TM [40].

When performing these surgical techniques, it is also important to evaluate the malleus, especially if it has a medial disposition. In these cases, it is important to evaluate the ligaments that sustain the malleus and tensor tympani muscle; if necessary, the malleus should be released to regain mobility.

Blood supply

In our opinion, any incisions made to create the tympanomeatal flap should preserve malleus vascularization, as was proposed for malleovestibulopexy [16].

Clinical research

This new concept can change the way we consider some otologic pathologies. Our experience suggests that extensive myringosclerosis/tympanosclerosis behaves as ankylosis of the tympanicomalleal joint, which affects sound transmission. Furthermore, this concept may illuminate some external and middle ear congenital anomalies, and could, therefore, lead to new reconstructive approaches in these cases. If the concept of the tympanicomalleal joint had been described previously, better outcomes may have been obtained in earlier TM reconstructions.

Conclusions

The TM, especially the *pars tensa*, appears to be part of a joint (syndesmosis) that underwent evolutionary changes to improve sound transmission and protect the middle ear. Considering the TM as a joint may be useful in understanding its pathology and assisting future scientific studies regarding this anatomic region. This could facilitate development of more efficient reconstructive surgical techniques for these structures, namely myringoplasty, tympanoplasty, and EAM reconstruction.

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Compliance with ethical standards

Conflict of interest None of the authors have conflicts of interest to declare.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any animal studies performed by any of the authors.

Informed consent Written consent for donation was obtained from each individual prior to death.

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