Cone Beam CT Atlas of the Normal Suspensory Apparatus of the Middle Ear Ossicles

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Learning objectives

To illustrate the CBCT appearance of the normal suspensory apparatus of the middle ear ossicles.
Background

The middle ear or tympanic cavity is an air-filled space located in the temporal bone between the air-filled external ear and the fluid-filled inner ear. The middle ear contains a chain of 3 movable auditory ossicles, the malleus, incus and stapes. They are supported by the tympanic membrane, the anterior, superior and lateral malleal ligaments, the posterior incudal ligament, the tendons of the tensor tympani and stapedius muscles, and the annular ligament.

The primary function of the middle ear is to act as an impedance element between the air-filled external ear and the fluid-filled inner ear. When sound waves reach the tympanic membrane, their energy is converted into mechanical vibrations that lead to motion of the ossicular chain, resulting in motion of the stapedial footplate, generating a wave in the cochlea. The frequency of this wave determines which hair cells are stimulated to emit a neural signal to the brain, resulting in hearing.

Tympanic cavity

The middle ear is a six-sided cavity containing the 3 auditory ossicles supported by the tympanic membrane, the auditory ligaments, the tendons of the tensor tympani and stapedius muscles, and the annular ligament (Figure 1). The roof of the tympanic cavity is formed by a thin plate of bone, the tegmen tympani. The floor is formed by a thin plate of bone (fundus tympani) that separates the tympanic cavity from the jugular fossa. The lateral wall is mainly formed by the tympanic membrane and partly by a ring of bone on which the membrane is inserted. The ring is incomplete at its upper part, forming the notch of Rivinus. The medial wall is formed by the lateral wall of the inner ear. The posterior boundaries are formed by the mastoid and the anterior boundaries by the carotid canal.

The tympanic cavity can be divided into 3 subdivisions in the coronal plane, the epi-, meso- and hypotympanum. The epitympanum is the attic, formed by an imaginary line drawn between scutum and tympanic segment of the facial nerve. The mesotympanum is the middle part formed by the line between scutum and tympanic segment of the facial nerve and a line connecting the tympanic annulus and the base of the cochlear promontory. The hypotympanum is the lowest part of the tympanic cavity and lies below the line between tympanic annulus and the base of the cochlear promontory.

Auditory ossicles

The tympanic cavity contains 3 auditory ossicles, malleus, incus and stapes (Figure 2). The malleus is attached to the tympanic membrane and the stapes is connected to the fenestra vestibuli, traditionally referred to as the oval window. In between hangs the incus
connected to both ossicles by delicate articulations, the incudomalleolar joint and the incudostapedial joint.

The malleus, named after the resemblance to a hammer, consists of a head, neck and three processes, the manubrium, the anterior and lateral processes.

The incus, so named after his resemblance to an anvil, consists of a corpus and 2 crura (processes). The anterior part of the corpus articulates with the head of the malleus in a saddle-shaped diarthrosis. The 2 processes are positioned perpendicular to each other with the short process running almost horizontally backward and the long process descending nearly vertically and bending medially, ending in a little notch covered by cartilage, the lenticular process that articulates with the head of the stapes.

The stapes, called from its resemblance to a stirrup, consists of a head, neck, 2 crura and a base. In between the 2 crura lies the foramen obturatorium. The 2 crura diverge from the neck and are at their end connected to an oval plate that is fixed to the fenestra vestibuli by a ring of ligamentous fibers, the annular ligament.

**Suspensory apparatus**

The malleus, incus and stapes are located between the tympanic membrane and oval window, and are supported by the tympanic membrane, the anterior, superior and lateral malleal ligaments, the posterior incudal ligament, the tendons of the tensor tympani and stapedius muscles, and the annular ligament (Figure 3).

The malleus is supported by the superior, anterior and lateral malleal ligaments, the musculus tensor tympani tendon, the tympanic membrane and the incudomalleolar joint. The incus is supported by the posterior incudal ligament and two joints: the incudomalleolar and the incudostapedial joint. The stapes is supported by the stapedius tendon and the incudostapedial joint. We discuss these suspensory elements more in detail below.
Fig. 1: A schematic visualization of the tympanic cavity as a box after removal of the posterior wall with tympanic membrane (1) and malleus (2) on the lateral wall, incus (3), Eustachian tube (4) and tensor tympani tendon (5) at the level of the cochleariform process on the anterior wall, stapes (6) at the oval window (7) on the medial wall, pyramidal eminence (8) with stapedius tendon (9) attached to the neck of the stapes, jugular bulb (10), round window (11), cochlear promontory (12) with cochlea (13) and semicircular canals (14) shining through the medial wall of the tympanic cavity.

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Fig. 2: Consecutive axial 0,3 mm thick CBCT images through a normal middle ear showing the ossicular chain with malleus manubrium (1), neck (2), lateral process (3) and head (4); incus body (5) with short (6) and long process (7) and its lenticular process (8) articulating with the head of the stapes (9); anterior (10) and posterior crus (11) of the stapes and the foramen obturatorium (12).

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**Fig. 3:** A schematic visualization of the ossicular chain and its suspensory apparatus with malleus and its head (1), neck (2), lateral (3) and anterior process (4) and manubrium (5); incus with body (6), short (7) and long process (8) ending in the lenticular process (9); stapes with head (10), neck (11), anterior (12) and posterior crus (13) and footplate (14). The superior malleal ligament (15) inserts on the malleal head (1); the lateral malleal ligament (16), anterior malleal ligament (17) and tensor tympani tendon (18) insert on the malleal neck (2); the posterior incudal ligament (19) inserts on the incus short process (7); and the stapedius tendon (19) mostly inserts on the stapes neck (11).

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Imaging findings OR Procedure details

Since a few years CBCT is a new imaging modality for temporal bone imaging. CBCT utilizes a cone shaped X-ray with a two-dimensional detector, generating a 3D volumetric data set in a single 360° gantry rotation. Of this data reconstructions in any desired plane can be made. The advantages of CBCT over MDCT are the high spatial resolution and low radiation dose. It is also less sensitive for metallic and beam hardening artifacts because image acquisition is based on conventional radiographic images. The most important disadvantage of CBCT is its high sensitivity for motion artifacts because the patient has to hold the head perfectly still during the acquisition time of approximately 40s.

For this paper we obtained images from normal middle ears in patients examined for conductive contralateral hearing loss using a Newtom 5G CBCT. The patients were positioned in a supine position with fixation of the head to prevent motion artifacts. The parameters of our protocol are 110 kV, ±140 mAs, field of view 15x5 cm High Resolution and slice thickness 0,15 mm. Of these axial raw data images reconstructions in the axial and coronal planes were made using newtom 5G software with a slice thickness of respectively 0,3 mm and 1mm.

The axial images are excellent to see the anterior malleal ligament (AML), posterior incudal ligament (PIL) and the stapedius muscle tendon. Coronal images are excellent to see the superior malleal ligament (SML) and the lateral malleal ligament (LML). The tensor tympani muscle tendon is well seen on both (Table 1).

The AML is attached by one end to the malleal neck, just above the anterior process, and by the other end to the anterior tympanic wall. The PIL connects the incus short process to the incudal fossa (Figure 4). The SML runs from the roof of the epitympanic recess to the malleus head (Figure 5). The LML extends from the posterior part of the notch of Rivinus to the malleus neck (Figure 6).

The tensor tympani muscle arises from the cartilaginous (upper) portion of the auditory tube in which it is contained, then passes around the cochleariform process forming a sharp bend to end in a slender tendon that attaches to the neck of the malleus (Figure 7). The muscle belly of the tensor tympani muscle is found antero-inferior to the tympanic segment of the facial nerve.

The stapedius muscle, the smallest muscle in the human body, arises from the apex of the pyramidal eminence immediately behind the oval window, runs forward and inserts into the posterior surface of the neck of the stapes in the majority of patients (Figure 8). Occasionally it is inserted to the head or to the posterior crus of the stapes due to the
persistence of a greater or lesser degree of angulation between the tendon and the belly of the stapedius muscle during embryological development.

The ligaments of the middle ear have nothing but a suspensory function whereas the muscles of the middle ear also have a protective function. Contraction of the tensor tympani muscle pulls the malleus anteromedially, while contraction of the stapedius muscle pulls the stapes posteriorly. Both muscles pull in more or less opposite directions and they apply forces in a way that is perpendicular to the motion of the ossicular chain. Their contraction, stimulated by the acoustic reflex, is a protective mechanism that stiffens the ossicular chain, thereby reducing the amount of energy that is delivered to the inner ear. This mechanism is also responsible for the improvement of signal-to-noise ratio.
Fig. 4: Axial 0,3 mm thick CBCT image through a normal middle ear showing the posterior incudal ligament (1), fossa incudis (2), incus body (3) and its short process (4), malleus head (5), crus posterior of the stapes (6) and foramen ovale (7).

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Fig. 5: Coronal 1mm thick CBCT image through a normal middle ear showing the superior malleal ligament (1), malleus head (2), malleus neck (3), lateral malleal ligament (4), tensor tympani tendon (5) and tympanic membrane (6).

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Fig. 6: Coronal 1mm thick CBCT image through a normal middle ear showing the malleus neck (1), malleus head (2), lateral malleal ligament (3) and tensor tympani tendon (4).

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Fig. 7: Consecutive axial 0.3 mm thick CBCT images through a normal middle ear showing the tensor tympani muscle (white arrow) passing around the cochleariform process (black arrow) and inserting at the malleal neck.

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Fig. 8: Axial 0.3 mm thick CBCT image through a normal middle ear showing the malleus head (1), anterior malleal ligament (2), pyramidal eminence (3), stapedius muscle (4), stapedius tendon (5) and the stapes with its anterior (6) and posterior crus (7).

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**Table 1**: Origin and insertion of suspensory middle ear ligaments and tendons. AML indicates anterior malleal ligament; PIL, posterior incudal ligament; SML, superior malleal ligament; LML, lateral malleal ligament.

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Conclusion

CBCT is an excellent technique to visualize the entire suspensory apparatus of the ossicles in the middle ear. The knowledge and recognition of the suspensory ligaments and muscles is necessary because subtle thickening in ligamentous structures can be an indication of early inflammatory changes in an otherwise normal middle ear or can reflect fibrous tissue fixation in the setting of chronic otomastoid disease.
References

