What should you know about stapes?

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Stapes presents embryological and anatomical characteristics which differentiates it from other bones of the organism. Pathologies affecting this ossicle are varied and can be isolated or associated with other lesions of the ear.

The aims of our study are:

- To know the different stages of embryogenesis of the stapes.

- To know the normal anatomy of this ossicle based on high resolution computed tomography (CT), after proper reorientation in the "axial stapes" plane;

- To know the main pathologies affecting this ossicle and learning how to seek CT signs that orient the diagnosis towards each of these pathologies through a rich iconography.
Background

The stapes is the smallest bone of the human body. As a part of the ossicle chain, it transmits vibrations from the tympanic membrane to the cochlea in the inner ear. It presents embryological and morphological features that differentiate it from other bones in the body.

Embryological feature

The stapes is the first of the three ossicles to appear. At the 38th day of embryonic life, the stapes is developed from the mesenchyma of the 2nd branchial arch. The upper part gives the basis of the stapes, the lower part gives the head and crus of the stapes. Toward the end of the 4th month of fetal life: the stapes is ossified from a single point of the footplate and then extend to both branches and to the head. Toward the 6th month of fetal life, the stapes reaches the adult size and it is fully ossified except at the level of its vestibular part and at the level of the incudo-stapedial joint. Once ossified, the stapes will alleviate.

Morphological features

The stapes is composed of a head, a neck, two branches (an anterior crus and a posterior crus thicker than the anterior one) and a footplat (closing the oval window and how it is secured by an annular ligament)

The branches of the stapes and the footplate delimit the "obturator foramen".

The analysis of the stapes is difficult due to the thinness of its parts, and specific acquisition and reconstruction protocols with appropriate parameters are required. It can be the only affected ossicle. Anomalies of the other ossicles or the outer and inner ear structures can be associated in complex malformations. In numerous studies, the average length of the entire bone was about 3.7mm, while the average breadth was about 2.7mm. The shape of the obturator foramen is most often triangular. The axial stapes plane is perpendicular to the footplate and allows better appreciation of the thickness of the footplate by limiting the zoom effects related to CT detectors. The footplate mean thickness is strictly less than 0.5 mm.
Findings and procedure details

We evaluated 35 patients with conductive hearing loss or mixed hearing loss, but with normal findings in the tympanic membrane. Thirty two patients underwent CT scans. HRCT scan imaging was performed using inframillimetric incidences. Stapes was studied in the stapes axial plane obtained after a triple orientation. Twenty seven patients underwent ossicular reconstruction and stapes surgery at our department.

We compared CT results with per-operative findings. Pathologies of stapes were found in 22 patients:

*Malformations (n= 4) (fig 1 and fig 2)

The commonest congenital ossicular abnormalities are thought to include stapes fixation and incudostapedial discontinuity

Congenital malformation of the stapes can be isolated or association to other congenital malformation of the middle ear. Congenital anomalies of the middle ear can be classified into:

- Major when associated off the involvement of the tympanic membrane and external ear
- or minor, when there is an exclusive involvement of the middle ear.

Classification of congenital ossicular malformations (adapted from Teunissen and Cremers).

Class 1 (30,6 %): Ankylosis or isolated congenital fixation of the stapes:

- Footplate fixation
- Superstructure fixation

Class 2 (38,1%): Stapes ankylosis associated with other malformations of the ossicular chain:

- Deformitis of the incus and/or malleus, or aplasia of the long apophysis of the incus
- Bone fixation of the malleusand or incus

Class 3 (21,6%): Congenital anomalies of the ossicular chain with mobile stapes footplate:

- Disruption of the ossicular chain
- Epitympanic fixation
• Tympanic fixation

Class 4 (9.7%): Congenital aplasia or severe dysplasia of the oval and round windows

• Aplasia
• Dysplasia
• Prolapse of the facial nerve
• Persistence of stapedial artery

*Post traumatic lesions (n=3) (fig 3)

Post traumatic lesion of temporal bone can cause a joint damage or a fracture of stapes.

Joint damage

Joint injury is more frequent than ossicular fractures. It is almost associated with a fracture of the temporal bone.

· Incudostapedial luxation is a pathological spacing between the long apophysis of the anvil and the button of the stapes of more than 1mm or in comparison with the other ear

· Incudostapedial dislocation testify to a more severe trauma and joint lesions and it is a displacement of the anvil in the tympanic cavity either towards the back on the level of the aditus to mastoid antrum or toward the downwards in the hypotympan

· Vestibulostapedial luxation: Rare because of the solid insertion of the footplate to the oval window by the annular ligament.

Fractures of stapes are rare and often associated with joint lesions.

The fractures of the stapes may concern one or two branches (difficult to visualize because of their low radio opacity) or the footplate which seem on CT imaging as a discontinuity of the footplate associated with a flow of perilymphatic liquid through the fracture and/or pneumo labyrinth. The use of the stapedial plan seems to be more interesting to visualize the fracture.

*Otospongiosis (n=7) (fig 4):

Otospongiosis is a congenital or spontaneous-onset disease characterized by abnormal bone remodeling in the inner ear. It is a chronic inflammatory disease limited to the temporal bone, which causes metabolic derangement of the endochondral layer of the otic capsule.

Clinically, otospongiosis is characterized by progressive, sensorineural or mixed conductive dysacusis, and by the presence of tinnitus.
CT imaging confirms diagnosis, studies the extent of the lesions, specifies the anatomical conditions of surgery and evaluated the prognosis. Veillon classification divides sites and extension of otosclerosis based on finding on HRCT of the temporal bone into 6 types:

**IA:** Thickening and hypodensity of the stapes footplate (>0.6mm)

**IB:** isolated anterior fenestral hypodensity < 1mm.

**II:** isolated anterior fenestral hypodensity >1mm, without contact with the cochlea

**III:** Supramillimetric anterior fenestral hypodensity >1mm, hypodensity extends to the endosteum of cochlea

**IVa:** Pericochlear hypodensities

**IVb:** Perilabyrinthine hypodensities

**Tympanosclerosis (n= 4):**

It is a condition caused by calcification of tissues in the middle ear and characterized by a hyaline infiltration with deposits limestone intra - and extracellular in the submucosal connective tissue lining the ossicles, bony walls and the middle layer of the tympanic membrane.

It includes: myringosclerosis, tympanosclerosis node, ossicular osteosclerosis, ankylosis of the ossicular chain and fixation of the ossicles.

**Osteosclerosis** is a post-inflammatory calcified scar thickening of ossicles. The stapes is often reached by osteosclerosis confers an aspect of "too beautiful Stapes" on CT imaging (fig 5).

**Ankylosis of the ossicular chain:** Often, the CT imaging is normal, especially when the joint fusion of the ossicles is not calcified. When it is fibrous, ankylosis appears as a thickening tissue surrounding the ossicular chain. This thickening is non-specific because it cannot distinguish it from mucosal thickening (fig 6).

**Lytic damage caused by congenital cholesteatoma (n= 2) (fig 7):**

Cholesteatoma may be defined as skin in the wrong place, which causes middle ear chronic inflammation, leading to ossicles and bone erosion. Ossicular demineralization is frequently observed in CT imaging but it is not always correlated with peroperative finding. The destruction of the malleus and the stapes is relatively rare. The uncus is the most fragile ossicle and more particularly its long apophysis exposed to the ischaemic risk.

**Fibrous dysplasia (n = 1):**
Fibrous Dysplasia is a gradual replacement of the normal bone tissue by fibrous tissue. The three major radiographic classifications of fibrous dysplasia are: pagetoid (56 %), sclerotic (23 %) and cystic (21 %).

All the bones of the body can be achieved. The achievement of the temporal bone is frequent, can cause hearing loss by blocking ossicular chain.

**Osteogenesis imperfecta (n= 1) (fig 8 and fig 9):**

Osteogenesis imperfecta (also known as brittle bone disease, or "Lobstein syndrome") is a congenital bone disorder characterized by brittle bones that are prone to fracture. There are 8 types of osteogenesis imperfecta:

- mild: type I
- perinatal lethal: type II,
- progressive deforming: type III
- Types IV to VIII are variable in severity and uncommon

Osteogenesis imperfecta may be responsible of sensorineural or conductive dysacusis. The dysacusis may be caused by an obliteration of the oval window as in Otosclerosis, or by the presence thin ossicle with a bad vestibulostapedial contact or by an ossicular fracture.

CT imaging shows bilateral perilabyrinthine hypodensities and hypertrophic bone formations. The achievement of long bones is very common in osteogenesis imperfecta.
Fig. 1: Aplasia of stapes and the long apophysis of the incus. Multiplanar reconstruction (A) with MIP, (B) and (C) without MIP: Absence aof the long apophysis of the incus (blue arrow) and bsence of the stapes (red arrow)

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Fig. 2: CT imaging of temporal bone: Bilateral agenesis of the stapes and vestibular windows

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**Fig. 3:** Axial plan of CT imaging of temporal bone: Separation of the head of the stapes from its branches (blue arrow)

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Fig. 4: Multiplanar reconstruction at the plan of the stapes: Thickening and hypodensity of the footplate (0.8mm)

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**Fig. 5:** Multiplanar CT reconstruction: irregular thickening and hyperdensity of the stapes (red arrow)

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**Fig. 6:** Multiplanar reconstruction CT imaging: Thickening and densification of the footplate (red arrow) and the posterior branch of the stapes (blue arrow): stapediovestibular ankylosis.

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**Fig. 7:** Multiplanar reconstruction sagittal (A) and oblique plane (B and C) Right middle ear otitis with cholesteatoma responsible of lysis of the long apophysis of the incus (green arrow) and of the stapes (red arrow)
**Fig. 8:** 25 years old, rheumatic fever, bilateral dysacusis, many bones fractures and blue sclerae

**Fig. 9:** CT imaging of temporal bone: Thickening of footplate (blue arrow) Per operative findings: vestibulo stpedial ankylosis (Lobstein syndrome)
Conclusion

Congenital and acquired lesions of the stapes are well known and have been widely described. They are rare but varied, and they can be isolated or associated with other lesions of the ear. A good knowledge of the normal Anatomy of the stapes is necessary to detect the pathologies of this ossicle.
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