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Descriptive anatomy of the human auditory tube

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Summary: The aim of this study was to correlate current morphologic data relating to the lumen of the auditory tube. Four methods were used: dissection under the operating microscope; microendoscopy of the tubal lumen; optical and electron microscope histology; and MR or CT imaging. The auditory tube consists of two unequal cones, a small posterior third, fixed and osseous (protympanum), and a mobile fibrocartilaginous anterior two-thirds, both joined by the tubal isthmus, a short constriction which is pseudosphincteric at endoscopy. The tensor veli palatini muscle (TVPM) and the levator veli palatini muscle (LVPM) are the chief muscles that vary the tubal lumen of the fibrocartilaginous portion, which is collapsed at rest. CT and especially MR imaging allows their observation in static conditions. Serial histologic sections reveal the continuity between the TVPM and the tensor tympani muscle. The main cartilage framing the lumen varies in shape according to the level surveyed. The tubal mucosa is lined with an epithelium combining ciliated and mucus cells, involved in mucociliary drainage and gas exchanges in the auditory tube. These morphologic elements represent a basis for study of tubal physiology and for planning treatment in dysfunctions of the auditory tube.

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Anatomie descriptive de la lumière de la trompe auditive adulte humaine

Résumé : Ce travail a pour but la confrontation des données morphologiques actuelles concernant la lumière de la trompe auditive (tuba auditiva) ou trompe d'Eustache. 4 méthodes ont été utilisées: la dissection effectuée avec un microscope opératoire, la micro endoscopie de la lumière tubaire, l'histologie en microscopie optique et électronique, l'imagerie par résonance magnétique nucléaire ou tomodensitométrie. La trompe auditive est faite de deux cônes inégaux, l'un petit (1/3) postérieur, fixe et osseux (protympanum), l'autre plus allongé (2/3), mobile fibro-cartilagineux, réunis tous deux par l'isthme tubaire, étranglement court, pseudo-sphinctérien en endoscopie. Le muscle tenseur du voile du palais (MTVP) et le muscle élévateur du voile du palais sont les principaux muscles faisant varier la lumière tubaire de la portion fibro-cartilagineuse, colla~ée au repos. L'imagerie en TDM et surtout en IRM permet de les observer de façon statique. Les coupes sériées en histologie révèlent la continuité entre le MTVP et le muscle tenseur du tympan. Le cartilage principal, armature de la lumière a une forme variable suivant la hauteur considérée. La muqueuse tubaire est tapissée d'un épithélium associant cellules ciliées et cellules à mucus, participant au drainage muco-ciliaire et aux échanges gazeux de la trompe auditive. Ces éléments morphologiques représentent une base pour l'étude de la physiologie tubaire, et l'orientation thérapeutique des dysfonctions de la trompe auditive.

Key words: Auditory tube — Tubal lumen — Levator muscle of the soft palate — Tensor muscle of the soft palate

The auditory tube is a narrow osteocartilaginous channel connecting the tympanic cavity with the nasal cavity 16, 13]. It is part of an anatomic and functional entity comprising the nasal fossae, nasopharynx and tympanomastoid cavities [2, 18]. Its lumen allows the passage of two different physical substances: one gaseous, air, and the other fluid, mucus [1]. This transluminal circulation resulting in an equalization of pressures on either side of the tympanic membrane, together with, as a corollary, the sound transmission by air conduction optimal for the subject [5, 10]. The aim of this study was to demonstrate the principal current morphologic data concerning the tubal lumen in order to understand its physiology and hence to plan the approaches to treatment for dysfunctions of the auditory tube.

Material and methods

Four different methods were used for this study:

– Dissection was performed on 6 normal adult head extremities (3 men and 2 women), previously fixed in 10% formol. These dissections were made under a Wild-Leitz operating microscope with cold light and variable magnification. A lateral infratemporal and posterior approach was used. The cartilages and the peritubal muscles (tensor veli palatini and levator veli palatini mm.) were particularly studied in their attachments and courses. Parallel sections perpendicular to the tubal axis were made in 3 frozen cephalic specimens.

– Microendoscopy of the tubal lumen was initially made on the anatomic specimens to assess the technical possibilities of the method. Six healthy adult volunteers subjects were also observed. The Olympus microendoscope prototypes of 0.8 to 1 mm diameter were fragile supple fibers, capable of orientation, with cold light. Simple local anesthesia was necessary in adults. In the live subjects the shape of the lumen of the two parts of the tube, the tubal isthmus, and the appearance of the mucosa were observed.

– Histology for optical and electron microscopy was performed on 5 normal fresh unfixed adult head extremities. The specimens of tubal mucosa were taken under vision near the tubal ostium and at 1 cm at the interior of the lumen. Variations in shape of the tubal lumen were noted depending on the level of the section studied, as also the cellular composition of the epithelium and connective tissue. Classical staining methods such as HES (hematoxylin, eosin, saffron) were used or more specific stains of the Weigert type to allow study of the cartilaginous structure; the density of the elastic fibers of the cartilage could thus be assessed.

– Imaging was performed in the living subjects in order to avoid any artefacts that might be found in the dissected anatomic specimens. CT studies were made in 15 adult subjects without any middle ear disease. There were 11 men and 4 women of mean age 45 years (range 16 - 64 years). MRI studies were made on 15 adult subjects without otologic disease (12 men, 3 women, all aged over 30 years). The CT examination was made with a Somaton Plus 5 type of Siemens apparatus allowing the performance of thin (3 mm) adjacent slices in two planes, one axial and parallel to the tubal axis and the other coronal and at right angles to this axis. The oblique axial plane allowed study of the auditory tube in its entirety. This plane was measured as 36° on avera-

Fig. 1
Frontal section of tympanic ostium of protympanum (operating microscope x 10). *T* tympanic cavity, *M* condylar process of mandible, *C* carotid canal

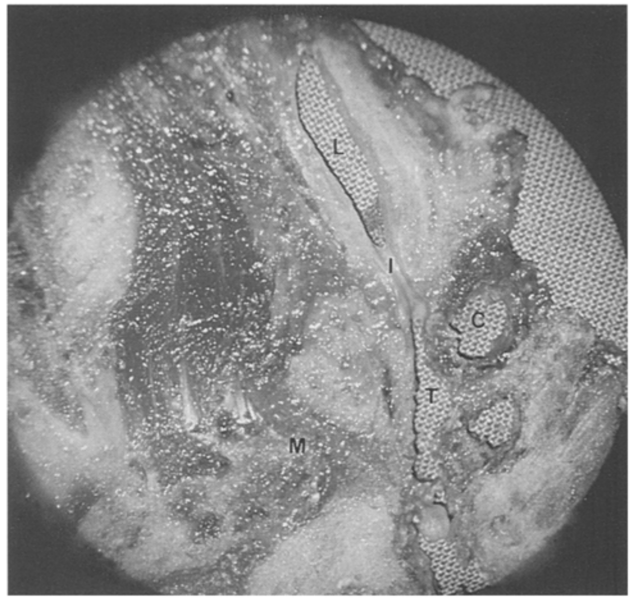

Fig. 2
Horizontal oblique section through tubal lumen (operating microscope x 6). *M* condylar process of mandible, *C* carotid canal, *I* isthmus of auditory tube, *T* tympanic cavity, *L* lumen of cartilaginous tube

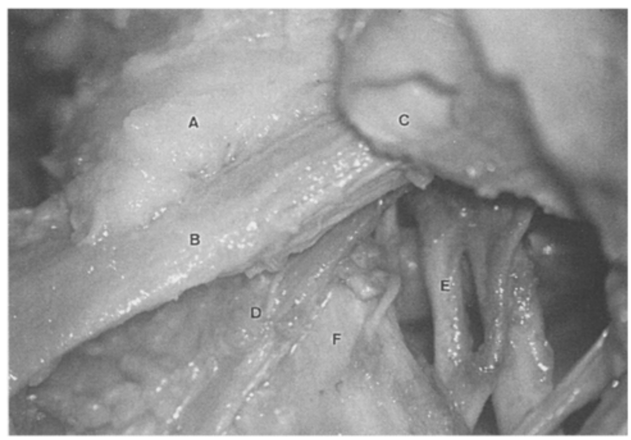

Fig. 3
Postero-inferior view of cartilaginous auditory tube (operating microscope x 10). *A* medial lamina of tubal cartilage, *B* levator veli palatini m., *C* internal carotid a., *D* tensor veli palatini m., *E* mandibular n. (V3), *F* medial pterygoid m.

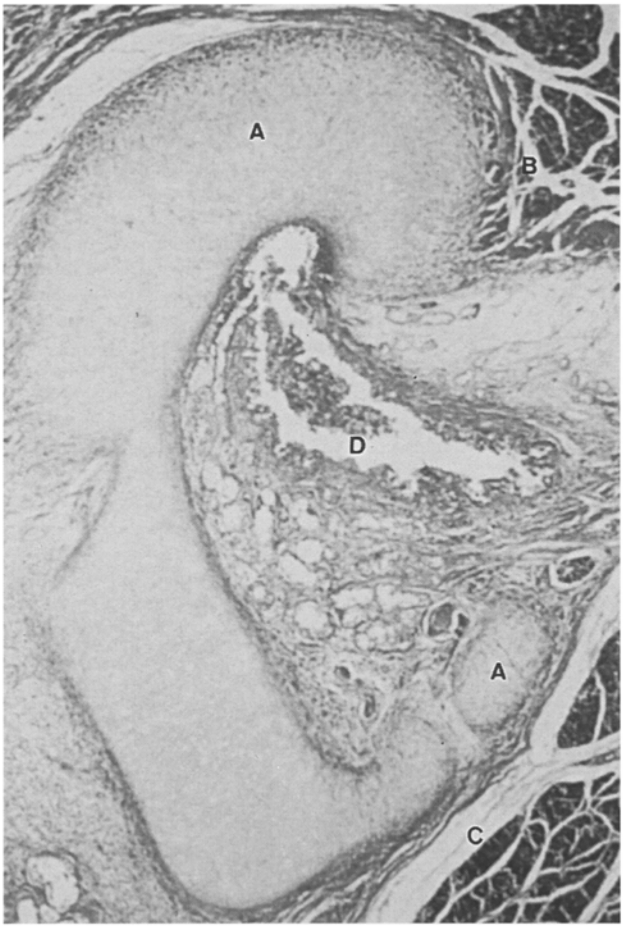

Fig. 4
Frontal section of cartilaginous auditory tube (optical microscope x 50) (*left side*). *A* tubal cartilage and accessory cartilage, *B* tensor veli palatini m., *C* levator veli palatini m., *D* mucosa of lumen and its folds

ge (range 31-40°) in relation to the bony palate, consistent with previous radio-anatomic studies showing a mean radiologic angle of 34° [12, 14]. The examination was made during apnea. MRI was performed using a Magneton SP 40 type of Siemens apparatus and an Expert Siemens type with a magnetic field of 1 Tesla. T1 and T2-weighted sequences were obtained without apnea (rapid acquisition time, matrix 512), with injection of gadolinium in 10 subjects. The planes of the sections were identical with those of the CT study. No dynamic tubal functional test of the Valsalva type could be made because of the short acquisition time.

Results

General topographic analysis

The origin of the auditory tube corresponds to the tympanic orifice of the protympanum, the anterior recess of the tympanic cavity, hollowed out in the petrous part of the temporal bone (Fig. 1). The course of the bony canal or protympanum, which is piriform with a short fixed posterior base, is constricted at the tubal isthmus. This isthmus is situated between the carotid canal and the temporomandibular joint. The channel expands in its mobile fibrocartilaginous portion. It ends in the pharyngeal ostium on the lateral wall of the nasopharynx which is closed at rest, and becomes an elliptic or triangular aperture with a superior apex in movement. The general shape of the auditory tube thus resembles an hourglass made of two unequal cones: one small, the posterior third, bony and fixed, the other elongated, the anterior two-thirds, fibrocartilaginous and mobile. They are connected by their constricted ends at the tubal isthmus (Fig. 2). CT imaging of the 15 normal subjects studied gave the axes of orientation of the protympanum. The tubal axis formed an average angle of 36° with the horizontal plane of the bony palate taken as a reference (range 31 40°). The tubal axis was angled to the sagittal plane at an average of 42° (range 33 - 50°). The mean diameter of the tympanic orifice was 4 mm (range 2 - 6 mm) and that of the tubal isthmus was 1.5 mm (range 1 - 4 mm). The radio-anatomic correlations in the coronal and axial oblique planes were recorded (Fig. 5a,b).

The peritubal muscles

The tensor veli palatini m. (TVPM) and the levator veli palatini m. (LVPM) are the two essential muscles that can cause changes in the tubal lumen (Fig. 3). The TVPM in its superficial lateral part is attached to the skull base along a line extending from the spine of the sphenoid behind to the lateral aspect of the upper part of the medial lamina of the pterygoid process in front. The muscle fibers form a triangular sheet with its base above and apex below, which is reflected at the pterygoid hamulus. The TVPM in its deep medial part is inserted at the lateral lamina of the main cartilaginous portion of the auditory tube (Fig. 4). Becoming tendinous after leaving the pterygoid hamulus, the muscle terminates at the posterior border of the bony palate in front and the aponeurosis of the soft palate behind. The serial histologic sections showed the relations of the cartilage and peritubal mm., also the continuity of the TVPM with the tensor tympani m. In the T1-weighted sequence, MRI identified the TVPM as a fine edge in hyposignal on the lateral aspect of the tubal cartilage (Fig. 5b). The LVPM has a double insertion: bony in front of the carotid canal and cartilaginous at the medial lamina of the tubal cartilage (Fig. 3). In its anterior two-thirds the LVPM has no direct relation with the auditory tube. It terminates by spreading as a fan on the dorsal aspect of the soft palate. In the MRI T1-weighted sequence the LVPM was not always distinguishable from the cartilage, though it was sometimes visible as an infracartilaginous hyposignal. The T2-weighted sequence provided no further information. No dynamic images could be obtained because of the short acquisition time.

The tubal cartilage

The tubal cartilage constitutes the supporting framework of the tubal lumen. It consists of a main portion and some

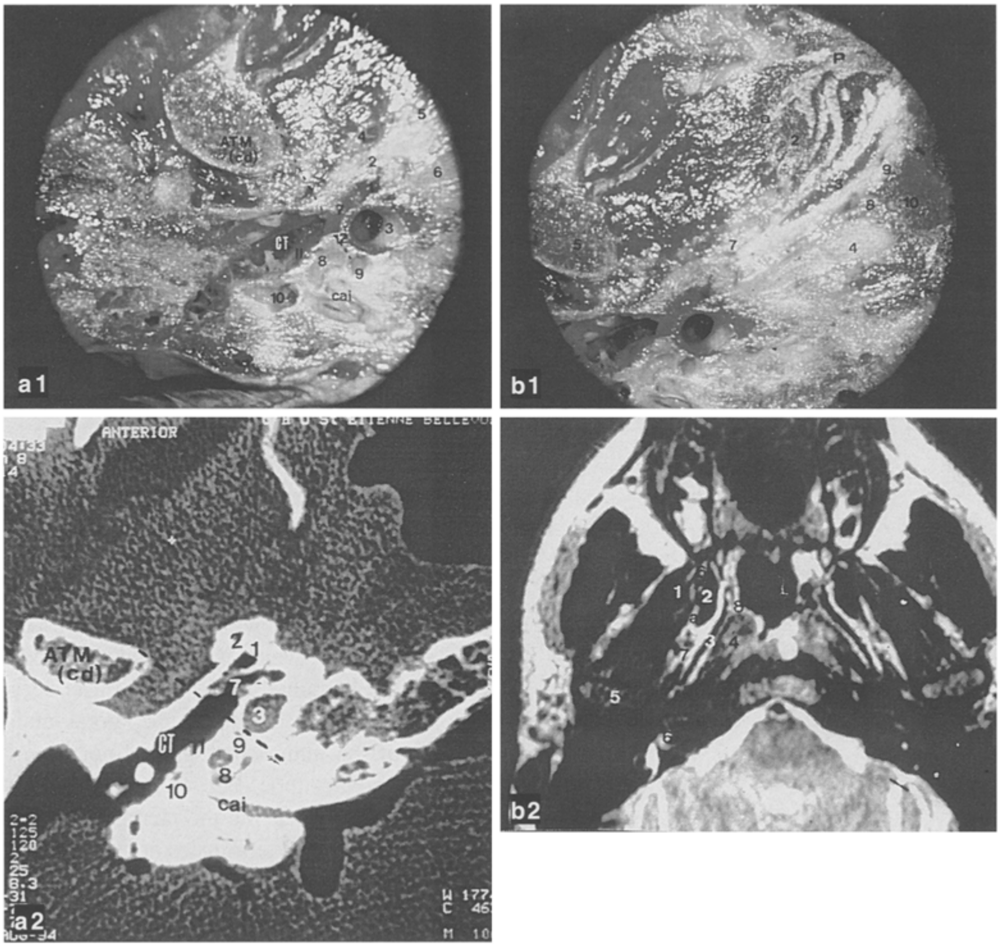

Fig. 5a1-b2
a1 Correlations between anatomy and axial oblique CT (30 - 50° in relation to horizontal plane, right side) Operating microscope x 6. **a2** *1*, tubal isthmus; *2*, spine of sphenoid bone, *3*, internal carotid a. *4*, middle meningeal a.; *5*, mandibular n.; *6*, main tubal cartilage; *7*, protympanum; *8*, cochlea, *9*, anterior semi-circular canal; *10*, labyrinthine vestibule; *11*, promontory; *12*, labyrinthine intercarotid space. *ATM*, condylar process of mandible and temporomandibular joint; *IAC*, internal acoustic meatus; *TC*, tympanic cavity; *dotted*, location of protympanum between labyrinthine intercarotid space and anterior border of condylar process **b1** Correlations between anatomy and oblique axial MRI (30 to 50° in relation to horizontal plane, right side). Operating microscope x 6 **b2** MRI. *1*, lateral pterygoid m.; *2,2**, the two bundles of the medial pterygoid m.; *3*, TVPM; *4*, main tubal cartilage; *5*, condylar process of mandible; *6*, internal carotid a.; *7*, cellulo-adipose space separating TVPM and pterygoid mm.; *8*, pharyngeal ostium of auditory tube; *9*, pharyngobasilar fascia; *10*, torus of LVPM; *a*, interpterygoid aponeurosis; *b* , pterygoid process

small accessory cartilages (Fig. 4). The main cartilage appears as a triangular lamina with a post-isthmic apex ensheathed in bone. It has an inferior concavity and two unequal slopes: the medial lamina, the larger, descends lower than the lateral lamina and marks the pharyngeal ostium of the tube. In serial histologic sections at right angles to the tubal axis the cartilage appears in the isthmic region as a plaque of variable thickness between the canal of the tensor tympan m. above and the rounded tubal lumen below. In the middle and lower parts of the tube the cartilage acquires the shape of a hook with an inferolateral concavity, marking an elongated lumen (Fig. 4). Histologically, after Weigert staining to show the elastic fibers, the hinge of the cartilaginous laminae exhibits a marked density of such fibers compared with the distal part of the laminae (Fig. 6). In MRI T1-weighted sequence the tubal cartilage appears as a relative hypersignal on the medial aspect of the tensor veli palatini m. (Fig. 5b).

The tubal mucosa

This is not identical from the protympanum to the pharyngeal ostium. The mucosa of the protympanum consists of a ciliated cylindrocubical epithelium resting on a basement membrane. The mucus glands and cells are poorly developed, as is the lymphoid infiltration. The connective tissue is not very thick and is represented by a dense fibrous collagen layer. The mucosa of the fibrocartilaginous portion of the tube consists of a ciliated pseudo stratified epithelium of respiratory type. This epithelium rests on a wavy basement membrane, forming "tubal folds" which are particularly in evidence on the inferior wall and may correspond to a "reserve" of mucosa facilitating opening of the tube (Fig. 4). Mucus cells and accessory glands are more numerous here than in the protympanum. The electron microscope shows the co-existence of mucus and ciliated cells bordered by plasmic membranes containing desmosomes (Fig. 7). They represent the morphologic substrate of the mucociliary drainage system of the auditory tube.

The tubal lumen properly so-called

Tubal microendoscopy traverses the lumen from its pharyngeal orifice to the tympanic cavity (32 - 44 mm). It reveals a delicate mucosa which is pink in life. At rest the tubal lumen is collapsed and opens during swallowing in particular. The tubal isthmus represents a short pseudosphincteric constriction of less than 1 mm diameter on average between the two more dilated zones: mobile and fibrocartilaginous below, bony and fixed above (Fig. 8). The histologic and microanatomic sections show the morphologic differences: the protympanum has a rectangular lumen surrounded by the petrous bone, overhanging the carotid canal (Fig. 1). The mobile isthmic and pre-isthmic zone has a rounded or oval lumen, bounded above by the tubal carti-

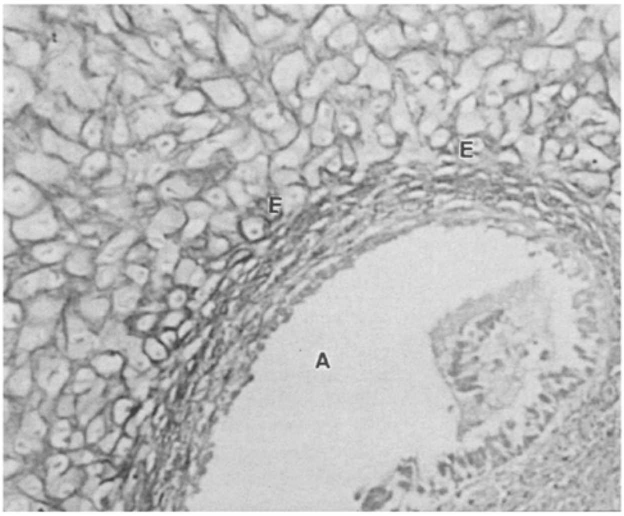

Fig. 6
Tubal cartilage between lateral and medial laminae (optical microscope x 10, Weigert stain). *A*, tubal lumen; *E*, marked density of elastic fibers

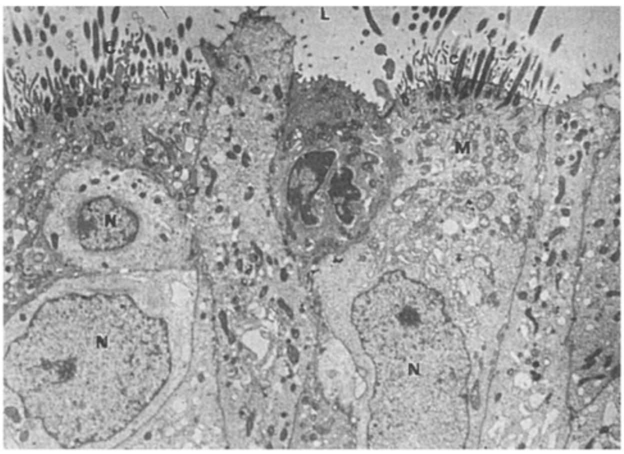

Fig. 7
Epithelium of tubal mucosa, cartilaginous portion (electron microscope x 6700). *L*, tubal lumen; *C*, cilia at apex of cell, *M*, mitochondria; *N*, nucleus

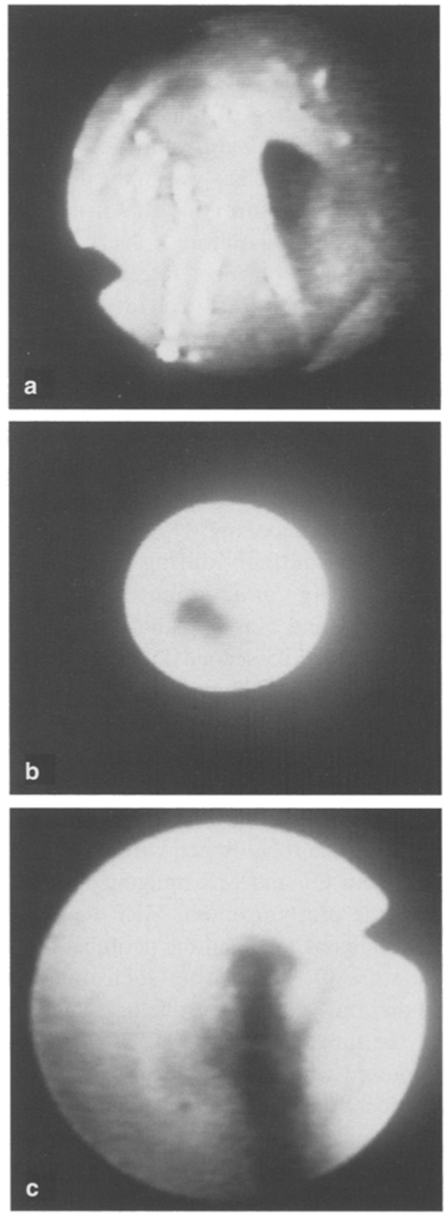

Fig. 8a-c
Microendoscopy of tubal lumen (Olympus fiber of 0.8 mm diameter). **a** lumen of cartilaginous tube. **b** lumen of tubal isthmus. **c** lumen of tympanic orifice of protympanum

lage and the canal of the tensor tympani m. and below by the LVPM. The lower pre-ostial cartilaginous segment has an elongated lumen with numerous inferior mucosal folds, surrounded by a glandular connective tissue with abundant glands (Fig. 4), which be come more numerous on progressing towards the pharyngeal ostium. The TVPM covers the cartilaginous hook above and laterally; medially, varyingly abundant cellulo-adipose masses constitute the classical fatty body of Ostmann. CT analyses the bony lumen of the protympanum (Fig. 5a). MRI reveals the musculocartilaginous borders of the lumen of the fibrocartilaginous portion (Fig. 5b).

Discussion

Morphologic study of the tubal lumen is an essential basis for understanding the complex physiology of the auditory tube, which has three main functions: ventilation, drainage and protection of the cavities of the middle ear l5, 10]. The gaseous equilibrium of this pneumatic system is ensured by a double mechanism. Air exchange with the nasopharynx by means of rhythmic tubal opening corresponds to the dynamics of the fibrocartilaginous and muscular portion of the tube, explaining the morphologic importance of these structures. Gaseous diffusion across the mucosa of the middle ear involves the entirety of the tubo-tympano-mastoid cavities [9, 15, 16]. Air exchange and gaseous diffusion lead to equivalence of pressure on either side of the tympanic membrane, essential for optimal audition by air conduction [5, 10].

Clearance of the entirety of the cavities of the middle ear is dependent on the mucociliary system of the mucosa l7l. Studies of the distribution of ciliated and mucus cells show their preferential presence in the lower part of the cartilaginous auditory tube, where there also exist, as our study shows (Fig. 4) numerous mucosal folds [8, 11, 20]. The lower part of the tubal lumen is thus more related to mucociliary drainage, whereas the main function of the upper part of the lumen is ventilatory [17, 2]. In fact, the cartilaginous hinge of the tube, rich in elastic fibers as shown by Weigert staining (Fig. 6), is also responsible for ope-

ning in the lower part of the lumen. The functions of ventilation and mucociliary drainage are actually interdependent and any disturbance of one reacts on the other, creating tubal dysfunction [1, 10, 16]. Morphologic analysis of the different anatomic structures involved in these functions may therefore be very important in clinical practice. Recent anatomofunctional studies provide a better understanding of tubal opening:
– microcinematography [9] and tubal microendoscopy [4, 21] reveal that the auditory tube exhibits luminal collapse in the resting state. Swallowing and yawning are the main factors responsible for its rhythmic opening. However, it does not open routinely during each act of swallowing and sometimes even contracts and closes. Tubal opening is very brief (0.25 seconds), related to the biomechanics of the peritubal muscles. It allows the introduction of 1µl of air into the pneumatic system of the middle ear 500 to 1000 times a day (30 times an hour), thus aiding equipressure [9]; – study of the tubal lumen currently benefits from CT and MR imaging. CT studies the pro-tympanum, MRI the fibrocartilaginous tube and the peritubal musculature [9, 12, 14] but such imaging allows only a static morphologic analysis of the tubal lumen. In CT, this may be confused with the sphenopetrous fissure, but identification of the oval and spinous foramina and the foramen lacerum allows identification of the bony fissure. The auditory tube, properly so-called, is below the plane of the greater wing of the sphenoid bone. Opening of its lumen is dependent on the tripartite muscle of Bluestone and Klein [2]: the tensor tympani m., tensor veli palatini m. (lateral part of the TVPM) and the dilator m. of the auditory tube (medial part of the TVPM), of common trigeminal innervation [3, 5]. This continuity of the muscle fibers of the TVPM and the tensor tympani m. is observable in the serial sec tions at optical microscopy. The attachments of the TVPM to the lateral lamina of the tubal cartilage and its fibrocartilaginous hinge zone allow downward and lateral tilting of the cartilaginous hook and active tubal opening [2, 3]. At the same time, the fibers of the tensor tympani m. regulate the tension of the tympanic membrane. The LVPM has a more accessory role in tubal opening [13], acting mainly on the tubal ostium and lower third of the tube, displacing the medial cartilaginous lamina upward and backward. This phenomenon can be observed at microendoscopy. Conversely, tubal closure occurs by passive parietal approximation, facilitated by the tubal fibroelastic structures [17, 20], the fatty body of Ostmann and the medial pterygoid m. applied closely to the lateral aspect of the TVPM [3]. During tubal dysfunction, imaging and micro-endoscopy may reveal in particular an extrinsic or intrinsic luminal obstruction, abnormal tubal gaping, or cartilaginous or muscular lesions [4,19]. Histologic study of the mucosa may show inflammatory infiltration of the connective tissue, epithelial lesions marked by impoverishment of the ciliated cells, an increase in the mucus glands and cells, or metaplasia [7, 11, 20].

In conclusion, besides the functional tests of current clinical practice (tympanometry, sono tubal manometry, etc), the entirety of the current morphologic data concerning the lumen of the auditory tube allows confirmation of the etiology of a tubal dysfunction. This provides a guide to treatment, whether medical by automatic manosonic aerosols, kinesitherapy, etc, or surgical.

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