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Review Article

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Tensor Tympani Muscle: A (Voluntary) Impedence Modulator In Mammals?

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Abstract

At the present time, the function of the Tensor Tympani Muscle (TTM) remains unknown. It seems to share many movements in common with the Tensor Veli Palatini (TVP) muscle, so one of the main hypotheses accredited in the literature interprets the TTM as a muscle that, together with the TVP, produces internal deflection of the tympanic membrane breaking the mucous membrane seal of the isthmus of the Eustachian tube, thereby contributing to middle ear ventilation. Some authors have demonstrated its response to loud sounds and vocalizations, chewing, swallowing and external stimulation of the facial muscles.

In the authors' opinion, and based on evolutionary and physiological considerations, it is possible that the TTM might have acted in mammals to create favourable compliance and impedance conditions in the tympano-ossicular system, so as to hear and transmit high frequency sounds and ultrasounds. Clearly, that function of impedance modulator in humans would have been lost, due to the absence of a sensorineural system to analyse ultrasounds.

Keywords: Tensor tympani muscle; Tympano-ossicular system; Ultrasounds; Impedance modulator

Introduction

Anatomically, the Tensor Tympani Muscle (TTM) is a long, thin muscle located in a bone semi canal that accompanies the bony section of the Eustachian tube from above and posteriorly. It extends laterally and dorsally to form a tendon oriented perpendicularly to its fibres in the cochlear form process and inserted into the neck of the malleus.

At the present time, the function of the TTM remains unknown. One of the main hypotheses accredited in the literature interprets the TTM, together with the Tensor Veli Palatini (TVP), as part of the same anatomic unit [1]. There is an evident phylogenetic connection with respect to the innervation, irrigation and formation of the structures of the throat and ear, including the Eustachian tube. In particular, the TTM and TVP share the common innervation of the motor branch of the trigeminal mandibular (V3) [2]. Their close anatomical relationship was also proved electromyographically. In fact, the TTM and TVP work simultaneously during swallowing, assisting in ventilation of the Eustachian tube in a manner similar to an air pump. The TTM, during its reciprocal contraction with the TVP muscle, thus produces an internal deflection of the tympanic membrane, which appears to break the mucous membrane seal of the isthmus of the Eustachian tube. This action should help to expel air and ventilate the middle ear [3].

TTM is even considered to be serving as a baroreceptor trigger by playing a proprioceptor role from its muscle length, which can be modified by hypotonia during low pressures of the tympanic cavity (gas exchange) and which retracts the tympanic membrane medially and, in turn, retracts the malleus due to the higher external ambient pressure. This malleolar movement makes the TTM hypotonic and would trigger a reflex mechanism from its muscle spindles to the trigeminal motor nucleus, initiating contraction of this muscle and the TVP; the contraction would open the Eustachian tube and aerate the tympanic cavity [4].

Other authors, emphasizing that fibres from the tympanic plexus nerves reach the TTM and innervate it, hypothesized this additional nerve supply to the TTM as chiefly the sympathetic nerve which sets up the sympathetic outflow on stimulation by tympanic glomus bodies as a result of CO_2 excess during hypoxia of the tympanic cleft. Misurya (1976) [5] coined the term 'tuner' for the TTM because of its possible functions as modulator and activator of the TVP.

Other theories relate to the protective role of the TTM against loud sound. A tensor tympani reflex, in response to loud sound, seems to be present in a minority of people [6].

A reflex response by the TTM to a startle stimulus has been described in the [7,8]. This has been elicited by using an air jet against the closed eye, or even by threatening the subject with a pistol [7,9].

Tensor tympani contraction has also been associated with vocalization, chewing, swallowing and movements of the facial muscles [7].

On the basis of all these hypotheses, it seems quite difficult to establish the real function of the TTM regarding the physiology of the human ear. In particular, it should be noted that its absence does not induce any aural changes. In fact, during surgery of the middle ear, it may often be necessary to resect the TTM's tendon to completely remove disease; interestingly, no aural dysfunction has ever been noted after resection of the TTM tendon [10-12]. Data in the literature are also confirmed by our surgical experience, during which we never found any complication arising in the post-operative period after resection of the TTM tendon during a tympanoplasty even after performing rigour-hearing tests.

So apparently, this muscle does not seem to play a particular role in the functionality of the human ear.

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The Hypotheses about TTM Function

Evolution of middle ear and high frequency hearing

The middle ear developed during evolution, in particular, in mammals [13]. Although studies from the 1950s and 1960s stated that ultrasounds are not transmitted by the middle ear due to a poor impedance match [14,15], it is thought, and nowadays widely accepted, that the middle ear developed because it could guarantee optimum hearing for high frequencies: the presence of an air filled cavity, isolated from the outside by a tympanic membrane, and containing an ossicular chain, would help in identifying and amplifying higher frequencies, just as produced by insects during flight [16].

This would have provided an evolutionary advantage to animals with such a hearing structure and given them increased ability in food hunting, because the ancestors of mammals were mainly insectivorous, and night-hunters [16]. In fact, mammals are unique among vertebrates in their ability to hear high-frequency sounds. While reptiles, amphibians, and most fish do not hear sounds above 5-7 kHz, and birds do not hear sounds above 8-12 kHz, mammals have upper frequency limits of hearing that range from 10 kHz (for the elephant) to 90 kHz (for the wild mouse), and even higher for some species that use echolocation [12]. The maximum audible frequency of the human ear is approximately 24 kHz via air conduction, and the frequency range above this is regarded as the ultrasonic range [17].

The role of compliance in sound transmission

The complex physiology of sound transmission through the middle ear must intuitively require a certain degree of compliance of that system to obtain an appropriate reception of mechanical waves that propagate in the air with a wavelength of microns or even angstroms [18]. Since all of the structures composing the middle ear have been relatively preserved throughout evolution (ossicles, temporal bone and middle ear pneumatization, tympanic membrane, TTM), it is also likely that each may play a role in such a delicate task.

The effect of graded variations in middle ear pressure on ossicular vibration was measured by Murakami et al. (1997) [19] in 15 normal human temporal bone specimens. The displacement amplitude of the umbo and stapes head was measured at 16 frequencies between 0.2 and 3.5 kHz at a constant sound pressure of 134 dB SPL at the tympanic membrane. Both negative and positive pressures decreased umbo and stapes vibration at low frequencies and slightly increased the vibration at higher frequencies. The effects were greater for negative pressure than for positive pressure. The change in stapes vibration was less than that of the umbo at low frequencies, but increased at higher frequencies: it was postulated by the same authors that these effects were primarily due to an increased stiffness of the tympanic membrane and a damping of ossicular vibration, due to stretching of the ossicular suspensory ligaments and the annular ligament of the footplate. More recently, other scientists have demonstrated, again using temporal bone specimens, that while there was a reduction in sound transmission at lower frequencies, a slight increase in umbo displacement magnitude occurred at frequencies of 7-8 kHz for middle ear pressures of -10 and -20 mmH_2O [20].

Although these experiments were performed by varying middle ear pressure, rather than by studying the role of the TTM in that impedance modulation, their results could also be translated to the TTM, if it was considered to be a muscle that could increase or decrease impedance conditions in the tympano-ossicular chain system.

The hypothesis

It seems intuitive to the present authors that if the middle ear with all its structure developed owing to its advantages at higher frequencies, its integrity would probably be useful mainly and uniquely for those frequencies. For instance, otologists commonly find that removal of most of the ossicular chain, such as the incus and malleus, and their replacement with single-ossicle prostheses is very often associated with only a very mild hearing loss in the frequencies routinely tested (i.e. 125 to 8000 Hz, those of the classic audiometry exam). In fact, higher frequencies are not tested due to their minor importance in daily life, but we cannot exclude a marked impairment on high frequency transmission in the case of TTM resection, as this has never been tested until now to our knowledge.

From what has been said above, in the authors' opinion, it is possible that the TTM could act to create, possibly even by a voluntary contraction, a favourable compliance and impedance conditions in the middle ear of mammals to hear and transmit high frequency sounds.

How to test the hypothesis

Higher frequencies are only rarely testable for a number of reasons, such as the relevant prevalence of presbiacusis (which primarily affects higher frequencies) in the general population, and the lack of appropriate instrumentation and routine in testing frequencies higher than 8000 Hz. Moreover, by definition, humans are not able to hear ultrasounds, due to the lack of an appropriate sensorineural organ: only when ultrasound at frequencies lower than 120 kHz is delivered via bone conduction can it create an auditory sensation, but with regard to the perceptual characteristics, several differences have been reported between bone-conducted ultrasound and air-conducted audible sound; for instance, the subjective pitch is independent of the frequency of bone-conducted ultrasound [17].

So to test this hypothesis, it would be necessary to quantify and measure with modern instruments and methods (i.e. by laser Doppler vibrometers), ossicular chain or tympanic membrane vibrations to frequencies higher than the audible spectrum of humans, while varying TTM contraction in some way [18]. If the hypothesis was correct, an optimal vibration of the tympanic membrane or ossicular chain would be verified in high frequency stimulation in the case of TTM contraction. An animal model would be more difficult to obtain, since it would be necessary to investigate hearing variation by conditioned audiometry for ultrasounds. While modifying TTM contractions (e.g. by sectioning), a behavioural response to administration of stimuli should be provoked after adequate conditioning.

Conclusion

Based on the present hypothesis, it is possible that the TTM might act in mammals to create a favourable compliance and impedance conditions in the tympano-ossicular system, so as to hear and transmit high frequency sounds and ultrasounds. Clearly, that function of impedance modulator in humans would have lost its role, due to the absence of a sensorineural system to analyse ultrasounds.

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