Dynamics of the Human Middle Ear

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Introduction

The dynamic behavior of the middle ear in vivo can only be investigated to a very limited degree. Since the passive functionality of the middle ear is quite well preserved over a certain time post mortem (within 24 h) the living ears were substituted by fresh temporal bones in order to study the passive middle ear mechanics. These data will be used to develop a virtual model of the middle ear that allows simulations of pathologic changes in it's structures or the functionality of new prostheses which replace certain middle ear components. This poster outlines three sub-projects that yield important information about the mechanics of the middle ear which are essential to develop the model.

Material and Method

In order to model the mechanics of the middle ear, it's functionality was investigated by means of a Scanning Laser Doppler Vibrometer (Fig.1). Temporal bones of fresh cadavers were prepared by replacing the outer ear canal by an artificial steel chamber and by preparing a surgical access to the middle ear structures such as the tympanic membrane (Fig.2) and the incudo-malleolar joint (Fig.3). The acoustic stimulus was generated by a small loudspeaker attached to the steel chamber (Fig.2).

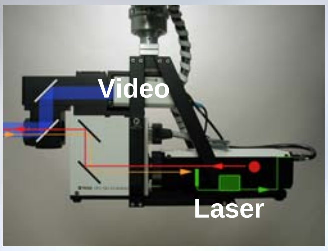


Fig.1: *The measuring head: The laser beam and the video image are coaxially aligned. The reflected laser beam contains the velocity component of the reading point.*

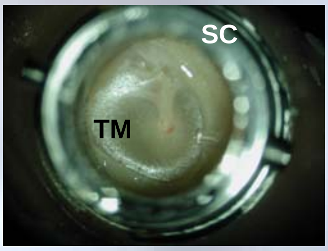


Fig.2: *Image of the tympanic membrane (TM) recorded by the video camera before the measurement. A steel chamber (SC) replaces the outer ear canal.*

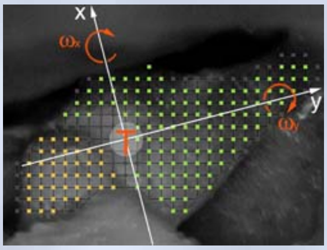
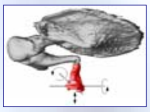
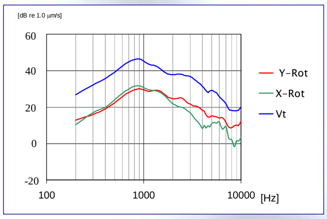


Fig.3: *View on the incudo-malleolar joint. Each ossicle was supposed to have only three degrees of freedom, one translational (T) and two rotational (ωx, ωy) components.*

Stapes motion



The stapes is the most proximal ossicle of the middle ear ossicular chain and represents the entrance to the inner ear, where the sensory cells are located. Analyzing its mobility is therefore necessary to understand how energy is transferred to the inner ear. Due to boundary conditions the stapes behaves as a rigid body with a reduced set of degrees of freedom: one translational and two rotational (Fig.4). The measured stapes velocity is therefore decomposed into these 3 main directions (Graph.1).



Graph.1: *3 velocity components*

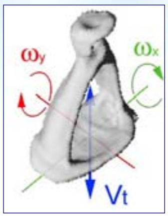
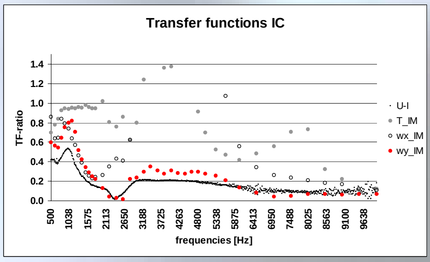


Fig.4: *3 degrees of freedom*

Incudo-malleolar Joint

Malleus and Incus compose a lever system which contribute to the impedance matching between the air and the inner ear fluid. The characteristics of the pressure transfer from the outer ear to the inner ear is given by the middle ear transfer function (TF). Since we split the motion into three components a transfer function can be developed separately for each omponent. The measurements revealed that that the TF of the rotatory component ωy coincides very well with the TF measured between the Umbo (center of tympanic membrane) and the Incus (Graph 2).

Graph 2: *The transfer function (TF) of the three velocity components (**T, ωx, ωy**) a the incudo-malleolar joint are compared to he TF between the Umbo and the Incus (**U-I** measured through a tympanic membrane perforation). The component **ωy** matches the TF between the Umbo and the Incus fairly well.*



Tympanic Membrane

The tympanic membrane (TM) transforms sound waves into mecanical movements by means of its vibrating properties. From a theoretical point of view a vibrating structure is completely characterized by its modal parameters: natural frequencies, modal damping factors and vibrating mode shapes. The modal parameters of a human tympanic membrane were extracted in a frequency range from 200 Hz to 5000 Hz. The mode shapes are complex (Fig.5 to Fig.8), i.e., each part of the TM will reach its own maximum deflection at a different instant within the vibration cycle.

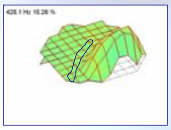


Fig.5: *428,1 Hz 1st mode shape*

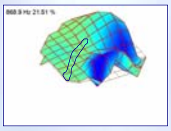


Fig.6: *868,9 Hz 3rd mode shape*

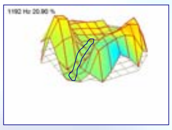


Fig.7: *1191.5 Hz 4th mode shape*

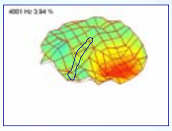


Fig.8: *4000.8 Hz 7th mode shape*

Natural Frequencies:	
1st =>	428.1 Hz
2nd =>	611.9 Hz
3rd =>	868.9 Hz
4th =>	1191.5 Hz
5th =>	1686.7 Hz
6th =>	3032.5 Hz
7th =>	4000.8 Hz

Tab.1: *natural frequencies of the tympanic membrane*

Conclusions

- The stapes shows a complex movement pattern. The translational velocity is 20 dB higher than both rotational velocities; above 2 kHz the Y-rotational velocity increases it's contribution.
- The incudo-malleolar joint is mobile within the physiological boundaries of hearing and is therefore a reasonable candidate for energy loss while sound is transmitted to the inner ear .
- The tympanic membrane has a complex vibrational structure. Several natural frequencies and complex mode shapes have been detected. They define the amount of energy entering the middle ear.