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Abstract Book

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1.1
Keynote Lecture

Overview and recent advances in bone conduction physiology
S. Stenfelt, Göteborg; Sweden

During the mid 18th century it was found that sound could be transmitted through solids and in the 19th century it was generally accepted that a person can perceive sound by bone conduction. Since then, the research community has tried to understand its fundamental mechanisms. Although the knowledge about bone conduction physiology continuously increases, all mechanisms involved are still not completely understood. The current status of bone conduction physiology including some recent advances will be presented. By the use of human temporal bone specimen models together with live humans, intact human cadavers, and isolated human cadaver heads, the sound in the ear canal, the vibration of the middle ear ossicles, oval and round window, and basilar membrane were investigated while applying vibration stimulation mimicking bone conduction excitation. Results from these investigations have shown that as long as the ear canal is open, the ear canal sound pressure is not a dominant contributor to perception of bone conduction sound. With an occluded ear canal the ear canal sound pressure becomes dominant at frequencies below 1 to 2 kHz; the occlusion effect depends on both the position of the occlusion in the ear canal itself and on the stimulation position. The inertia of the middle ear ossicles seems to contribute to the bone conducted sound around and slightly above the resonance frequency of the ossicles (around 1.5 kHz). At low and high frequencies, the stimulation of the basilar membrane with bone conduction excitation is most probably not through the oval window; inertia of the fluid dominates at the low frequencies while a combination of fluid inertia and compressional and expansion of the cochlear space can produce the response at the high frequencies. Vibration analysis as well as tone cancellation experiments indicate that the internal structures of the inner ear produces no important response for bone conduction hearing. The sound wave transmission in the skull base differs from the cranial vault and the transcranial transmission is practically one for frequencies below 1 kHz while it decreases with around 10-20 dB/decade at higher frequencies. These presented results influence methodology for hearing threshold testing with bone conduction stimulation as well as usage of bone conduction hearing aids.

1.3
Invited Paper

The Bone anchored hearing aid (BAHA) and elicited skull vibrations
M. Bance, O. Majdalewieh, R. van Wijhe, Halifax; Canada

Objectives: To measure the skull vibration characteristics of the BAHA in plastic, dried, and for the first time, live human skulls, and to compare different models of the BAHA. Methods: Using a laser Doppler vibrometer, vibration responses with sound input of 70-80 dB SPL were measured on unloaded BAHAs, a dry skull, a plastic skull, and on the abutments of three live BAHA-fitted patients. Responses at different volume settings and distances from the vibrator were also tested. Frequency responses were calculated for displacement, velocity, and acceleration. Loss of vibrations across the snap coupling was measured Results: Unloaded BAHA accelerations were about 30-50 dB higher than live head accelerations. Live head accelerations were similar to dry skulls in frequencies above 500 Hz, but much higher than the plastic skull responses. Live head responses were more damped. The Cordelle II® outperformed the other two processors by about 20 dB. The Classic 300® had better low frequency responses than the Compact®. The volume settings had little effect on vibration output overall. Acceleration peak was at approximately 2.5 kHz for all conditions. The snap coupling was an efficient coupling from the transducer to the skull. Conclusions: The BAHA processors differ in the output acceleration they can achieve with differing loads. The volume control setting has little impact on accelerations produced for most processors. The live head responses are similar to the dry skull above 500 Hz.

2.1
Keynote Lecture

Middle ear static pressure: measurement, regulation and effects on middle ear mechanics
J. Dirckx, Antwerp; Belgium

The middle ear (ME) is a rigid biological gas pocket which is closed most of the time. It is believed that the pressure in the ME is regulated by a complex combined action of the Eustachian tube muscles, eardrum deformation and gas exchange through the blood circulating in its walls. External changes can cause abrupt pressure variations, and sudden pressure variations of thousands of kPa occur in everyday situations. To understand the mechanisms and effects involved with quasi-static high amplitude pressure variations, we need to know how ME pressure varies in normal circumstances, investigate both fast and slow regulation mechanisms, and determine the effect of such pressures on middle ear mechanics. We will introduce some recent work performed in these three fields, which will be discussed further by other contributors, and discuss in more detail some recent results we obtained on mechanics of ossicle motion induced by static pressure. To determine the normal variations in ME pressure, we developed a monitoring system which is used in ambulant patients. We will show some results from direct measurements in intact ears. To investigate a possible fast regulation process, we performed measurements of eardrum deformation in gerbils. We found that volume displacement of the pars flaccida is small compared to middle ear volume, so the its fast pressure regulating function is limited to a very small pressure range. As to slow regulation processes, we will introduce a new technique for measuring rates of gas exchange in rabbit ears. The method works at constant pressure, so no baroreceptors are triggered which may influence the process. The method allows to determine the "pumping" rate at which the blood constantly removes gas from the ME cavity. In more detail, we will discuss some recent results, obtained in rabbits, of the effect of static pressure variations on middle ear ossicle motions. With heterodyne interferometry, we measured motions of umbo and stapes at pressure change rates between 200Pa/s and 1.5kPa/s. We will show that hysteresis in these motions increases as pressure change rate decreases, quite in opposite to the common notion that such hysteresis is mainly caused by visco elasticity. We conclude that static and dynamic friction are important aspects of ossicle motion at slow pressure variations, new aspects which should be taken into account when trying to model quasi-static ossicle mechanics. Finally, we will introduce some 3-D measurements of ossicle displacement, measured with X-ray tomography.

2.2

Ossicular motion during static pressure changes in the avian middle ear

R. Mills, J. Zhang, M. Zadrozniak, Edinburgh; Scotland

Purpose: To investigate the hypothesis that birds are likely to have a 'decoupling' mechanism' within the midde ear to cope with changes in static pressure.

Method: We have investigated the motion the single ossicle found in the middle ears of four different species of birds (pheasant, Phasianus colchicus; gannet, Morus basanus; rock dove, Columba livia and glaucous gull, Larus hyperborius) using captured video clips during changes in the pressure in the external auditory meatus between +100 and -100 dPa. The middle ear structures were examined via a posterior approach to the middle ear and the pressure was changed using a manual tympanometer (Amplaid, Italy) connected to a sealed external auditory meatus. The magnitude of the pressure changes generated was confirmed using a Testo digital pressure guage.

Results: In the avian middle ear the off centre attachment of the extracolumella to the tympanic membrane and flexion of the joint between the extracolumella and columella results in rocking of the foot plate rather than direct excursion in and out of the vestibule.

Conclusion: We postulate that this is a protective mechanism to avoid excessive displacement of the footplate into the vestibule during changes in middle ear pressure and that it is analogous to the ossicular 'decoupling' observed in the human middle ear in the same circumstances.

2.3

Direct measurements and monitoring of middle ear pressure

H. Jacobsen[1], J. Dirckx[2], M. Gaihede[1] , K. Tveteras[1]

Aalborg; Denmark[1], Antwerp; Belgium[2]

Purpose: The normal function of the middle ear depends on the maintenance of a pressure close to ambient pressure. However, deviation in middle ear pressure (MEP) is a common finding in otitis media and related sequelae, and hence, it is considered a major pathogenetic factor. Up till now, available date were either obtained from indirect measurements, resulting in limited accuracy, or from short term acute experiments, or from longer term measurements in ears with perforated eardrums. The purpose of the present study was to introduce a new improved method for direct accurate monitoring of MEP in ambulant humans with intact ear-drums.

Materials and Methods: A new method is presented, where a catheter was inserted into the mastoid through a small hole burred into its antero-lateral tip. Patients included were submit-ted for parotidectomy, where this region is routinely exposed. The catheter was connected to a high accuracy pressure transducer ($\pm$1 Pa), and data were stored in a portable unit, at a sam-pling rate of 10 Hz for up to 48 hours. Hence, MEP could be continuously monitored also after discharge from hospital for investigating pressure changes during daily life activities. The catheter was removed after 48 hours similarly to an ordinary drainage tube, and data transferred to a PC.

Results: Preliminary findings have illustrated pressure changes in relation to altitude changes (elevator trip), Eustachian tube openings, and supine position. The study is ongoing and addi-tional results including day-night variations and various other pressures challenges will be presented.

Conclusions: The method has showed high accuracy and capability of long term monitoring of MEP and it can be used also for studying the results of various pressure challenges as well as daily life fluctuations. Such data provide new information on the exact pressure variations of the middle ear and possibly of its regulation. Hence, these observations are likely to be valuable for the understanding of pressure regulation also in pathological ears.

2.5

Indications of central regulation of middle ear pressure from pressure evoked brain potentials

S. Sami[1], LG. Nielsen[1], M. Gaihede[1], AM. Drewes[2], Aalborg; Denmark [1, 2]

Purpose: In clinical practice, the presence of negative MEP is very common and most often related to secretory otitis media. Although pathological changes in the tympanic membrane may to be associated with impaired baroreceptor function little is known about the middle ears active regulation of pressure. New information on these aspects would be of major sig-nificance in otological research, and have been emphasised as goals of research. On this background we have designed a new experimental method for conducting pressure stimuli to the ear canal and investigated the pressure related early brain potentials in humans. Fur-thermore, we employed spatial analysis to localise the brain areas involved in the process-ing.
Materials and Methods: The experiments were conducted by stimulating the tympanic membrane with a novel ear computer controlled pressure triggering system for rapid synchronized pressure loads (˜3 kPa). In six adult subjects the resulting brain evoked responses were recorded from 64 surface electrodes using a standard EEG cap. A full band EEG acquisition method was adopted, signals were sampled at 20,000 Hz, and band-pass filtered between 0.05 and 3000 Hz. Results: The study showed the first ever recorded early pressure evoked potentials. The characteristics of the pressure evoked brain potentials and their individual topographic localization were reproducible. Source localization was adopted on a realistic head model to show the location of these early neural generators. The dipole model showed a residual variance lower than 5%, and it could be reliably applied to the individual data. The earliest dipolar activities were observed in the medulla followed by the activity, which was generated by the cerebellum.

Conclusions: Earlier experiments in primates have demonstrated anatomical and physio-logical associations between the tympanic plexus of the middle ear cavity, respiratory cen-tres in the brainstem (nucleus of the solitary tract) and the muscles of the ET. Thus, a neu-ral feedback mechanism controlling the MEP has been suggested. In agreement, our current findings showed an early activation of the brainstem in response to pressure stimulation of the TM and the middle ear. The additional activation of the cerebellum was assumed to play a role in controlling the activity of the Eustachian tube. Further studies in this line are likely to provide basic knowledge on the possible role of an overall neural control of the MEP.

2.6

Biomechanical evaluation of eustachian tube function and its role in regulating middle ear pressures

SN. Ghadiali[1] ED. Bell[1], CM. Alper[2], JD. Swarts[2], CD. Bluestone[2], Bethlehem[1], Pittsburgh[2]; USA

Purpose: The Eustachian tube (ET) is a collapsible respiratory airway which connects the nasopharynx (NP) with the middle ear (ME). In addition to other physiological functions, the ET is responsible for maintaining ambient pressures within the ME. The ET normally regulates ME pressures by periodically opening during swallowing and transporting gas between the NP and ME. However, the inability to open the ET results in sub-ambient ME pressures, fluid transudation into the ME and the development of persistent Otitis Media (OM). The goal of this study is to develop a mathematical/computational model of the opening and pressure regulation functions of the ET. These models have been correlated with experimental ME pressure measurements obtained in both healthy adults and young children with OM in order to identify the biomechanical properties that may be responsible for ET dysfunction.

Material and Methods: Cross-sectional histological images from temporal bone specimens were used to create anatomically-accurate finite element (FE) models of the ET's soft tissue structures (i.e. cartilage and fat tissue). The mechanical properties of the various tissue elements were based on direct experimental measurements and ET opening phenomena during swallowing was simulated by specifying an asynchronous muscle contraction sequence. Finally, molecular dynamics simulations were used to quantify the adhesive properties of glycoproteins in the ET. Changes in the open lumen area, ME pressure and air flow rate during swallowing were calculated and these parameters were compared with experimental measurements.

Results: For healthy adults, our models indicate that ET opening is a three-staged event. First, contraction of the levator veli palatini muscle (LVPM) results in a small decrease in lumen area (i.e lumen constriction). Second, contraction of the tensor veli palatini muscle (TVPM) results in a large dilation or opening of the ET lumen. Finally, sustained contraction of the LVPM can result in a post-swallow constriction of the ET lumen. In addition, our mathematical models indicate that the expression of mucoadhesive glycoprotiens during inflammatory OM can significantly increase mucosal adhesion forces and may therefore result in an inability to open the ET.

Conclusions: By correlating sophisticated mathematical models with experimental data, this study has provided important insights into the biomechanical mechanisms responsible for ET dysfunction. This work was supported by a grant from the NIH DC005345. SNG is a Parker B. Francis Fellow in Pulmonary Research.

2.8

The ossicular chain contributes to the effects of static pressure on middle-ear sound conduction

JJ. Rosowski[2], ML. Wood[1], Boston; USA [1,2]

Purpose: Trans-tympanic (between the ear canal and the middle ear) static-pressure differences have long been known to adversely effect hearing. It is generally believed that the primary effect of such pressure differences is to stress the tympanic membrane and ossicular system. Large static stresses (relative to the stresses associated with sounds) strain the mechanical processes that determine the sensitivity to sound with the result that the mobility of the middle- ear sound-conducting apparatus is decreased. Such a decrease in mobility implies a non-linear acousto-mechanical system whose response to sound is modulated by large static stresses and strains. The anatomical locations of the controlling nonlinear processes within the middle ear are not well described.

Materials& Methods: Measurements of middle-ear input admittance and sound-induced umbo velocity were measured in gerbils in which the middle-ear cavity pressure was varied between +/- 25 cm H2O re ambient pressure. Measurements were made before and after two ossicular modifications 1) interruption of the incudo-stapedial joint, 2) interruption of the bony anterior process of the malleus and the posterior incudo-ligament.

Results: The middle-ear input admittance and the sound-induced umbo velocity in normal ears are differently affected by trans-tympanic static pressures: These two mechanical measurements are most affected by pressures of different polarity. The umbo-velocity vs. static pressure tympanograms also show greater hysteresis than admittance tympanograms in the normal ear. The degree and sign of the asymmetry and the degree of hysteresis are greatly affected by interruption of the ossicular joints and ligaments.
Conclusions: The cochlea and the ossicular ligaments play a significant role in determining how the middle ear responds to sound while under static pressure loads. [Supported by NIDCD]

2.9

Subannular ventilation tubes in treatment of chronic tubal dysfunction – results in 85 consecutive cases

MG. Jensen, H. Jacobsen, M. Gaihede, J. Rosborg, Aalborg; Denmark

Purpose: The appearance of a negative middle ear pressure is well-known during the course of secretory otitis media and occasional complications like cholesteatoma, tympanic membrane retraction or atelectasis. The usual treatment is insertion of a ventilation tube into the tympanic membrane, a procedure that often has to be repeated, sometimes with insertion of long-term T-tubes. This, however, increases the risk of persisting tympanic membrane perforations, and in regard to T-tubes the rate can be higher than 20%. Hence, there is an obvious need for a method for long-term ventilation of the middle ear with minimal risk of persisting perforation. The objective of the present study is to describe the in situ lifetime of subannular ventilation tubes (SVT).

Material and methods: A retrospective study of patient files in a consecutive series of 85 patients, who underwent SVT insertion during the period from 1979 to 2004. A tympanotomy was performed and a small groove was burred in the bony annulus of the floor of the external ear canal. A subannular ventilation tube (Per-Lee© 60°-angle) was fitted and inserted into the groove, and the flap replaced. In this way the tube was positioned peripherally to the tympanic membrane itself. The in situ lifetime was determined for two groups; one in which the SVT's were still functional, and one in which they had been removed or extruded.

Results: In the group of functional SVT's the mean in situ lifetime was 59 months (SEM= 7.9; N=25), while in the group of removed or extruded SVT's it was 34 months (SEM=4.0; N=60). The average number of out-patient visits in the two groups was 4.7 and 6.7 per year, respectively. In the group of removed or extruded SVT's, a persisting perforation was found in 10 % of the cases.

Conclusion: The in situ lifetime of the SVT's was considerably longer compared to conventional ventilation tubes (mean 9 months) and T-tubes (mean 20 months). The SVT´s were kept functional by means of regular out-patient check-ups with removal of crusts and treatment of occasional episodes of otorrhoea. The rate of persisting perforation after extrusion or removal was smaller than for T-tubes.

3.1
Keynote Lecture

Recently developed measurement techniques and diagnostic apparatuses for the middle ear
H. Wada, Sendai; Japan

Compared with the cochlea, the middle ear is a relatively large organ, has a simple structure and is located close to the surface of the head. This means that the middle ear can be easily accessed. As a result, various kinds of measurement techniques have been developed and the middle ear function has been well analyzed and is understood to a great extent. When we speak, the amplitude of tympanic membrane vibrations is of nanometer order of two digits. This vibration is transmitted to the oval window of the cochlea by means of the three ossicles. The ossicles, which are supported by ligaments in the middle ear cavity, generally rotate around the axis between the anterior malleal ligament and the posterior incudal ligament, and the umbo and stapes have a piston-like movement. The main role of the middle ear is to match the low impedance of the air in the external auditory meatus to the high impedance of the cochlear fluids. In other words, the middle ear is an impedance transformer. Without this function, much of the sound energy would be reflected by the tympanic membrane. In my talk, among various measurement techniques and diagnostic apparatuses, I will focus on the following:

1. The middle ear function assessed by acoustic impedance meters such as conventional tympanometers with frequencies of 226 Hz and 1,000 Hz, a sweep frequency impedance meter, etc.

2. The dynamic behavior of the tympanic membrane and ossicles analyzed by laser Doppler velocimeters and the speckle interferometry technique.

3. Outcomes of ossicular chain mobility measured by diagnostic apparatuses (static and dynamic methods).

4. The function of the eustachian tube evaluated by an analyzer developed in Japan.

5. Effectiveness of finite element method analyses of the middle ear

3.2
On the way to differentially diagnosing middle-ear and inner-ear disorders
D. Turcanu, E. Dalhoff, A. Gummer, Tübingen; Germany

Laser Doppler vibrometry has proved to be very useful in diagnosing ossicular chain disorders by measuring the umbo velocity. Although it has been supposed that these measurements contain information about both the middle ear and the inner ear, it has not been possible to separate the information, to differentially diagnose middle- and inner-ear disorders. Here we propose a method to separate information about middle-ear and inner-ear components in records of vibration measurements on the human umbo. For this purpose, distortion product otoacoustic emissions (DPOAEs) were measured on the human eardrum using a very sensitive laser Doppler vibrometer. They proved to have a very stable phase behaviour but a highly fluctuating amplitude feature that was used to develop a parameter called the fluctuation ratio (FR). The FR is postulated to be an attribute of the cochlear amplifier and to have a specific input/output characteristic which is affected differentially by middle- and inner-ear disorders. It correlates with hearing threshold and predicts threshold with a standard deviation of only 8 dB. The predictability is improved when the eardrum transfer characteristic is taken into account. We believe that vibration measurements of DPOAE on the human eardrum can become a new tool for separating middle-ear from inner-ear disorders and for objective assessment of hearing threshold. Supported by the German Research Council, DFG GU 194/6-1 and partially by the European Commission, Marie Curie Training Site, HEARING (QLG3-CT-2001-60009).

3.3
Toward a further understanding of middle ear mechanism using otoreflectance
F. Zhao[1], J. Dayalan[2], R. Meredith[3], N. Wotherspoon[1], D. Keefe[4], Swansea; Wales[1], Waterford; Ireland[2], Singleton; Wales[3], Omaha; USA[4]

Otoreflectance (OR) is a newly developed hearing-test instrument utilizing acoustic signals presented and recorded in the ear canal. It provides calibrated measurements over a frequency range from 0.25 to 8 kHz of the transfer functions as reflectance and admittance, and the power absorbed by the ear canal and middle ear. In the present study, acoustic impedance and reflectance measurements were performed in 20 subjects with a clinical acoustic immittance instrument (GSI 33 version 2) and an experimental OR system. Measurements are made over a frequency range of 226, 678 and 1,000 Hz with the GSI middle ear analyser and 250-8,000 Hz with the experimental OR system. The reflectance patterns across a wide frequency range at ambient ear-canal air pressure are analysed. Moreover, the tympanometric admittance obtained with the two systems is compared. Because the measurement of OR is simple, fast, objective, reproducible and non-invasive, and because energy reflectance and absorbed power are relatively insensitive to the position of the probe in the ear canal, the OR tympanometry instruments may have a great potential for use in the general audiological and screening utility for diagnosing middle-ear pathology.

3.4

Determination of the specific acoustic input impedance of the ear for diagnostic of middle ear transmission disorders

J. Rodriguez Jorge[1], MM. Maassen[1], W. Hemmert[2], A. Gummer[1], HP. Zenner[1], Tübingen; Germany[1], Infineon Technologies AG[2]

Introduction: The information obtained through measurements of the acoustic impedance at the eardrum permit conclusions concerning middle-ear function.

Materials and Methods: We use the laser-doppler vibrometer (LDV) in combination with a microphone to evaluate the specific acoustic impedance (SAI) at the umbo. A commercial laser-Doppler vibrometer (Model OFV-3001 with an OFV- 302 sensor head, Polytec) is used for the measurements of the tympanic membrane. The laser is coupled to a standard operation microscope (OMPI MDM, ZEISS) with a 200 mm front lens, equipped with a continuous zoom with magnification factors from 0.6 to 2.4.

Results: The specific acoustic impedance response of the mean value of 55 male and 40 female subjects at 60 dB SPL is compared with patients with otosclerosis, malleus head fixation, luxation of the ossicels and after contraction of the stapedial muscle. One can observe that the middle ear is poorly adapted to low and high frequency range. The region between 700 Hz and 7 kHz has the smallest impedance amplitude. The two resonances, the first around 1 kHz and the second around 3 kHz, have the minimal impedance amplitude which could be 10 times larger than that of a plane wave in air. Displacements from the otosclerotic ear were distinguished by abnormal low amplitudes below 1 kHz proportionally to the hearing loss (-10 dB relative to normal subjects) and a distinct resonance around 2 kHz. In case of incomplete malleus head fixation, the calculated SAI versus frequency shows only the increase of impedance in low frequency ranges. The case of ossicular interruption, the impedance shows a high decrease in low frequency ranges and a frequency shift of the first resonace up to 500 Hz instead of around 1 kHz.

Conclusion: Here we describe a method for in vivo measurement of middle-ear dynamics based on vibrations of the tympanic membrane which consequently allows the determination of the specific acoustic input impedance of the ear and the differential diagnosis of middle ear pathology.

3.5

A new diagnostic apparatus for ossicular fixation: Evaluation of the usability through the measurements in human temporal bones and patients

T. Koike[1], S. Hamanishi[2], Y. Yuasa[3], R. Yuasa[3], T. Kobayashi[4], HH. Nakajima[5], W. Chien[5], M. Ravicz[5], SN. Merchant[5], JJ. Rosowski[5], RL. Goode[6], H. Wada[2], Tokyo[1], Sendai[2,3,4]; Japan, Boston[5], Stanford[6]; USA

The evaluation of ossicular mobility is an important parameter in decisions regarding surgical repairs of diseased ears as well as for post-surgical improvement in hearing level. To evaluate ossicular mobility in surgery, we have developed an apparatus that quasi-statically measures the load and displacement of the ossicles, where the compliance defined by the slope of the load-displacement curve has been used as an index of ossicular mobility. In a pilot study, this apparatus was used to measure the ossicular mobility in human temporal bones at the stapes and the malleus body before and after the ossicles were artificially fixed. These results were compared with simultaneous estimates of ossicular mobility obtained with a laser Doppler velocimeter (LDV). A correlation was seen between the ossicular mobility measured with our apparatus and the vibration amplitude of the ossicles. In addition, the ossicular mobility of three patients with otosclerosis or chronic otitis media was also measured to evaluate the usability of the apparatus. The apparatus can distinguish the differences in ossicular mobility between normal and fixed ossicles, and it makes estimating the change of mobility between pre- and post-treatments for ossicular fixation possible. Positive correlation was seen between ossicular mobility and hearing level. These results suggest that our apparatus has the ability to detect the difference in ossicular mobility quantitatively between fixed and normal ears, and gives support to the idea that our apparatus could be a useful tool in the surgical estimate of ossicular disorders.

3.6

Measurements of stapes velocity in live human ears

W. Chien[2], JJ. Rosowski[2], ME. Ravicz[1], SN. Merchant[2], Boston; USA[1,2]

Purpose: While there are many measurements of how the tympanic membranes of live humans respond to sound, few measurements of stapes velocity have been reported in live humans. Consequently, our understanding of human middle-ear transmission comes mostly from studies in live animal and human cadaveric ears.

Materials & Methods: In this study we used Laser-Doppler Vibrometry (LDV) to measure sound-induced stapes velocity intra-operatively in 10 patients undergoing cochlear implantation. These patients had no history of middle-ear pathology, and their ossicular chains appeared normal on intra-operative inspection and palpation. The measurement angle between the LDV beam and the direction of piston-like stapes motion was large (65-80 degrees).

Results: The raw Vs, the component of stapes velocity measured by the LDV (normalized by ear canal sound pressure), had a band-pass shape: roughly proportional to frequency below 700 Hz, flat between 700 Hz and 4 kHz, and decreasing at higher frequencies. The phase of the normalized Vs decreased smoothly from 0.2 periods at 300 Hz to -0.8 periods above 4 kHz. The mean Vs in the ten ears is similar to the mean of the 7 ears in the only published live human stapes velocity measurements [Huber et al., Ann. ORL 110: 31-35, 2003] and to Vs measured at similar measurement angles in 8 fresh cadaveric human temporal bones. When corrected by the cosine of the measurement angle below 2 kHz [Chien et al., Audiol. Neurotol., in press], Vs is stiffness-dominated at low frequencies and decreases at frequencies above a broad resonant peak near 1 kHz, similar to Vs measured at small measurement angles in cadaveric ears.

Conclusions: The LDV angle in measurements of stapes motion during cochlear-implant surgery is a significant frequency-dependent factor in understanding the measured velocity. With the proper measurement angle corrections, stapes velocity in live and cadaver ears are similar. [Supported by NIDCD]

3.7

Six years of experience with measurements of tympanic membrane velocity by laser Doppler vibrometry as a clinical diagnostic tool

SN. Merchant, HH. Nakajima, W. Chien, JJ. Rosowski, Boston; USA

Purpose: Laser Doppler Vibrometry can be used to measure tympanic membrane (TM) velocity in live patients. Since 1999, we have made such measurements in a prospective manner in over 50 normal subjects and over 150 patients with middle- or inner-ear disease in order to determine their clinical utility.

Material and Methods: The laser is focused on the umbo or a target on the TM, and the transfer function of TM velocity to ear canal sound pressure is measured in response to sound stimuli of 300 Hz to 6000 Hz range at intensities up to 90 dB SPL. We can make accurate, safe, repeatable and non-invasive measurements of TM motion within 5 to 10 minutes per ear.

Results and Conclusions:
(1) We have a normative data base of umbo velocity from 56 subjects with no history of middle ear disease, normal otoscopy, no air-bone gap on audiometry, and air and bone conduction thresholds less than or equal to 20 dB.
(2) Pre-surgical measurements of umbo velocity were made on 57 ears with fixed stapes, 5 ears with fixed mallei and 16 ears with ossicular interruptions. These pathologies were confirmed at middle ear surgery. Measurements were also made on 28 ears with superior canal dehiscence (SCD), which was confirmed either surgically or by CT scanning. We found that measurements of umbo velocity in conjunction with audiometry allowed reliable, pre-surgical diagnosis of ossicular pathology, and helped to differentiate SCD from ossicular fixation.
(3) We have made measurements of umbo velocity on 65 ears after stapedectomy, which have provided insight into the mechanics of a stapes prosthesis.
(4) We have measured TM velocity in 10 ears after type III tympanoplasty (TM graft applied to stapes head), which have enabled clinical differentiation of causes of postoperative air bone gaps such as non-aeration of the middle ear, fixation of the stapes, and loss of contact between the TM graft and stapes head.
[Supported by the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, USA]

3.8

Sources of variability in reflectance measurements on normal human ears

SE. Voss, NJ. Horton, RR. Woodbury, CA. Shea, Northampton; USA

Purpose: The development of acoustic reflectance measurements to augment middle-ear diagnostic testing may lead to noninvasive tests that provide information about the middle ear that is currently unavailable from standard audiometric testing. One factor limiting the development of diagnostic tests that rely on ear-canal reflectance measurements is that normal-hearing human ears show inter-subject variations of up to 10 dB between 100 and 4000 Hz and up to 25 dB between 4000 and 10000 Hz [e.g., Voss, S.E., and Allen, J.B. , 1994, "Measurement of acoustic impedance and reflectance in the human ear canal," J. Acoust. Soc. Am., 95, 372-384]. The work presented here aims to quantify inter-subject variability relative to intra-subject due to temporal changes in either an individual ear or the measurement system, methodological issues including estimates of ear-canal area, and measurement location within the ear canal.

Methods: Reflectance measurements were made on both live-human and human-cadaver ears.

Results: In live-human ears, reflectance was measured in five separate measurement sessions over a time period of four weeks in each of five human subjects (10 ears) to compare intra-subject versus inter-subject variability. The variability among ears from different subjects was significantly greater than the variability within repeated measurements on a single ear. Reflectance measurements in human-cadaver ears demonstrate that reflectance depends on both the ear-canal location and variations in the ear-canal area. However, these variations are also small relative to inter-subject variations.

Conclusions: Both sets of experiments suggest that intra-subject variability in reflectance measurements is not a significant factor in the observed inter-subject variability.

3.9

Higher frequency variability in external ear resonance – why so much and can we improve poor functioning ears?

R. Goode, Stanford; USA

Proposal: The external ear, composed of the pinna and external auditory canal (EAC) is well known to provide amplification of sound passing from the air around the head to the tympanic membrane (TM). The amount of gain in an adult ear is typically 15 to 25 dB SPL peaking near 2.7 kHz due primarily to the quarter-wave length resonance of the EAC. A secondary peak near 5.0 kHz of around 10 dB is also present thought due to conchal resonance. Considerable variation in gain exists at the higher frequencies above 2 to 3 kHz.; this variability can be as much as 20dB SPL.

The reasons for this variability are unclear in many cases but obviously contribute to the higher frequency hearing thresholds, particularly in sound field testing. Some external ears, like middle ears, are clearly better than others and their identification may not be possible by inspection, including otoscopy.

When hearing thresholds are normal with a normal cochlea and middle ear, these variations are of little significance; in cases of mild hearing loss, an improvement of 10 dB SPL or greater in the frequency range above 2 kHz could be beneficial. This could be particularly useful and convenient in patients scheduled for surgical correction of a middle ear conductive hearing loss, who are found on real ear sound pressure measurements to have poor external ear resonance. Correction of that deficiency, if possible, at the same time would have real value.

This paper will discuss causes of the variability as well as the potential for surgical or prosthetic correction once the cause(s) is identified.

Material and Methods: Review of the literature plus computer model experiments and real ear sound pressure measurements in normal and abnormal external ears (REUG).

Results: While the majority of normal appearing external ears resonate within a range of +5 to -5 dB SPL from mean values, some 10 to 20 % can be considered outliers over a relatively

broad higher frequency range above 2.0 kHz. As a general rule, the presence of a large and deep concha, a large pinna, and a large EAC opening correlate with higher gains and the opposite with lesser. If the latter can be partially converted to the former with a conchoplasty, improvement occurs. Passive in the ear prostheses also can provide improvement.

Conclusion: Assessment of external ear resonance in normal appearing ears may on occasion be helpful to the otologist in providing improved hearing thresholds.

4.1
Invited Paper

Closure of the ear canal opening and its effects on hearing tests
K. Gyo, T. Maetani, Matsuyama; Japan

Objective: Three issues concerning closure of the ear canal opening were investigated.
1) What kind of sound is heard by closure of the ear canal opening?
2) How far the sound is emitted to the ear canal during testing of bone conduction hearing? Is this affected by wearing an air-conduction receiver?
3) Does wearing an air-conduction receiver affect on the results of tinnitus match test?

Methods:
1) This study was conducted in 5 male volunteers. They were asked to express quality of sound heard by closure of the ear canal opening with a finger or by pouring water into the ear canal. Comparative sound was provided from the other side of the ear.
2) Twenty-two ears of 11 normal male volunteers were the subjects of this study. Effects of wearing an air-conduction receiver on emitted sound in the ear canal during bone-conduction testing were investigated.
3) This study was undergone in 25 patients suffering from unilateral tinnitus. Pitch match and loudness balance tests were performed by presenting comparative sounds to the uninvolved ear, with and without wearing an air-conduction receiver on the involved ear.

Results:
1) Sealing with a finger or water caused a tinnitus-like sound with an intensity of 17.2±4.5dB and 9.4±2.2dB, respectively. Both procedures induced sound similar to 125 Hz band-pass noise.
2) When a bone conduction receiver on the forehead is activated, sound pressure recorded in the ear canal was larger by wearing an air-conduction receiver by 17.9±4.9dB at 0.8 kHz, although it decreased at 2-4 kHz.
3) Pitch of the tinnitus was differently perceived by wearing the receiver in 9 of 25 patients (36%), while that of loudness in 15 patients (60%).

Conclusion: Closure of the ear canal opening affect variously on auditory testings. Therefore, careful attention should be paid in evaluating the results with closure of the ear canal.

4.2
Invited Paper

Estimation of stapes piston-motion with uni-directional measurements is prone to error
WF. Decraemer, Antwerp; Belgium

We have shown that the vibration of the stapes in human, cat and gerbil exhibits all 3-D components of translation and rotation, but also that non-piston components do not contribute to the transmission path. In most experiments access for direct measurement of stapes motion in line with the piston axis is not available and piston motion is estimated from single component interferometric measurements done under observation directions that make angles up to 50o with the piston axis. We used a heterodyne microscope/interferometer to measure the vibration velocity of the stapes in human, cat and gerbil from different observation angles and calculated the complete set of 3-D motion components for the stapes. Using micro CT scans of the experimental ears, we could express the components in an intrinsic reference system and foretell the motion component that will be obtained when a single axis interferometric measurement is done under various angles with the piston axis. For low frequencies (f<2kHz) a cosine factor provides a good correction for the axis off-set, at higher frequencies the piston component can not correctly be estimated from a single off- axis observation. We will show that this may lead to serious misinterpretations of experimental results.

4.3
Acoustic transmission properties of the eustachian tube
A. Khwaja, M. Bance, Halifax; Canada

Purpose: The human eustachian tube is poorly understood, despite being the cause of most chronic middle ear disease. There are few non-invasive tests of function. A new methods of assessment is sonotubometry, but the acoustic characteristics of the ET are poorly understood. Knowing how the ET and mastoid shape sound presented to the nasopharynx is important to developing these tests further. These parameters are also important for understanding patulous ET.

Methods: The acoustic transmission properties of the ET were measured in 1: A simple physical model of the ET and mastoid 2: Cadaveric hemi-heads 3: Explanted cadaveric ETs 4: Fresh human mastoids 5: Embalmed human mastoids.

Results: The simple physical model showed strong resonances which depended on the size of the mastoid cavity modeled. The cadaveric half-heads showed much more damped responses. The explanted cadaveric ET showed resonances similar to the physical model. The mastoid frequency response was much flatter than a simple syringe version of the same volume, and explains the damping of the resonances of the hemi-head compared to the simple physical model

Conclusions: The mastoid does not resonate in the same manner as a simple syringe cavity of the same size. This makes it difficult to use the resonant peaks of the ET as a measure of ET opening.

4.4

Experimental investigations on the functional effect of ossicular joint fixation

C. Offergeld[1], N. Lasurashvili[2], M. Bornitz[2], T. Beleites[2], T. Zahnert[2], Freiburg[1], Dresden[2]; Germany

Introduction: The protection and functional mechanism of the ossicular joints has been described in literature. The gliding ossicular joints reduce stapes displacement during atmospheric pressure changes in normal subjects. In cases of fixed ossicular joints unphysiological movements of the stapes can be assumed as static pressure is directly transferred towards the annular ligament. These movements could assumingly lead to disorders of the inner ear. Audiometric testing of ossicular joint fixation is difficult in clinical practise, therefore there is lack of knowledge about possible effects on static behaviour and acoustic transfer characteristics of the middle ear.

Materials and Methods: Experimental investigations were performed in 10 fresh temporal bone specimen. Dynamic measurements were performed using Laser-Doppler-Vibrometry (LDV) with determination of vibration amplitude of the stapes footplate before and after stepwise artificial fixation of the ossicular joints by cyanoacrylate glue. For static experiments standardized atmospheric pressure variations were applied through the sealed external ear canal while measuring stapes displacement using LDV.

Results: In cases of artificially fixed ossicular joints a shift of the resonance frequency was observed. Furthermore a decrease of the stapes vibration amplitude in the low frequency range of approximately 10 dB was evaluated whereas improvement of the transfer characteristics of up to 15 dB was demonstrable in the high frequency range. These findings were differently emphasized depending on the site of first fixation (incudo-stapedial vs. malleo-incudal joint). The stapes displacement evaluated an up to 5-fold increase compared to regular values after fixation of the ossicular joints under atmospheric pressure variations.

Conclusions: Ossicular fixation leads to significant changes in dynamic and static function of the middle ear. The amount of change, either from a dynamic as from a static point of view is depending on the specific ossicular joint involved. We conclude that ossicular joint fixation should be prevented during tympanoplasty, if possible.

4.5

Postoperative tympanogram in tympanoplasty with thin section cartilage island

CS. Cho, JS. Lee, DS. Chang, MS. Choi, KY. Park, Daejeon; Korea

The advantage of cartilage in tympanoplasty is mechanical stability, for this reason some surgeons are using it as material of grafting tympanic membrane. However it had been not widely used for its increasing mass and stiffness effect. To minimized this problem some authors had used cartilage by palisade, thin section cartilage plate or cartilage island technique. In present study, author designed thin section cartilage island, which is combined technique of thin section cartilage plate and cartilage island. Tympanogram could give us information on the tympanic membrane status of the rigidity and stiffness. The tympanometric findings of this technique were compared with those of ordinary temporalis fascia group. 101cases of thin section cartilage island and 50cases of temporalis fascia technique underwent tympanoplasty type I. Tragal cartilage was harvested and made thin section cartilage island by 0.3-0.4 mm thickness including perichondrium, measured by micrometer. The cases which were poor Eustachian tube function and reperforated were excluded. The rate of the static compliance less than 0.2ml, tympanometric width less than 60mmH2O was no significant stastic difference between temporalis fascia group and thin section cartilage island group. Type of tympanogram showed also no significant difference in both group. It makes us expect that thin section cartilage island could be a good material for tympanoplasty in aspect of stiffness and rigidity as well as mechanical stability.

5.1

Keynote Lecture

Mechanics of hearing in other species

D. Robert, Bristol; UK

Insects are marvelous. They are organisms that have diversified into a multiplicity of shapes and functions. It may not be all too surprising that their sensory systems, conveying a sense of boundless creativity, display a commensurately rich structural and functional diversity. The ears of insects are no different; they come in all shapes and forms. Audition in insects serves three basic functions: the detection and localisation of mates in the context of intraspecific communication, the detection and sometimes localisation, of aerial echolocating bats, and the detection and localisation of prey. Much research has addressed the structure, function and physiology involved in insect hearing (for a recent collection of reviews see Micr Res Tech, Topical Issue, 63, vol 6, 2004). Because of their diminutive size, insects are endowed with small ears forcibly set close together. This size limitation is the source of challenging constraints to achieve adequate audition, constraints that are exacerbated by the biophysics of sound propagation in the environment. Yet, small does not necessarily mean simple and inefficient; insect ears can be sharply adapted to the task and exhibit sophisticated processing capacities and mechanisms similar to those of the highly complex ears of mammals (Robert D, Göpfert MC 2002 Curr Opin Neurobiol 12:715-720). Using sensory ecological tenets wherever possible, several aspects will be addressed: 1. the peripheral mechanisms of frequency selectivity in locusts, 2. nanometer scale auditory sensitivity in mosquitoes and moths and (3) active and adaptive processes in insect hearing.

5.2

Invited Paper

The catenary principle of tympanic membrane function – time to put it to rest?

R. Goode, Stanford; USA

Proposal: Helmholtz in 1863 was the first to propose that part of the pressure transformation produced by the tympanic membrane (TM) was due to a conical lever action of the TM. This was also based on experiments to verify his theory that the radial collagen fibers within the TM connecting the annulus to the malleus handle produced a lever action so that sound pressure reaching the gently curved surface of the TM produced an increase in force at the apex of the TM. This theory was later called the cate-

nary theory based on an engineering principle in suspension bridges. Theories expressed by a genius must be taken seriously but questions were raised regarding this theory by Bekesy and later, and more convincingly, by Wever and Lawrence in l954. However, in 1972 Khanna and Tonndorf revived the concept stating it was the most important mechanism the TM had for impedance matching. Today, the concept was waned but is still mentioned in some texts. This paper will discuss the various experiments performed pro and con and attempt to put the concept into its proper place.

Material and Methods: Review of the literature Results Genius on both sides of the controversy. However, experiments and clinical results in reconstructed TMs support the fact that while this effect may exist to some extent in normal TM's, it is minor. Flat TMs do not have significant conductive hearing loss all else being equal and the effects of positive and negative pressure both show a loss in sound transmission, which would not be the case if the mechanism were active.

Conclusion: It is time to put the theory to rest.

5.3

Do non-piston components contribute to scala vestibuli pressure behind the footplate in gerbil?

WF. Decraemer[1], O. de la Rochefoucauld[2], W. Dong[2], EL. Olson[2], SM. Khanna[2], JJ. Dirckx[1], Antwerp; Belgium[1], New York; USA[2]

The stapes moves predominantly piston-like but at higher frequencies tilting of the footplate is also observed. The gain between the sound pressure in the earcanal and the acoustic pressure in the perilymph of the scala vestibuli close to the stapes is a smooth function of frequency while the frequency response of the piston component of the stapes, normalized to earcanal pressure, exhibits pronounced maxima and minima. We explored whether the tilting could fill in the gaps in the frequency response of the piston component to produce the smooth intracochlear pressure response. Young adult anesthetized mongolian gerbils were used: we first measured the scala vestibuli pressure using a micro-pressure sensor (Olson, JASA,1998) and then, using a confocal heterodyne interferometer, vibration velocity of the stapes was measured from different observation angles to allow for the calculation of the 3-D motion components (Decraemer, HR 1990). A micro-CT scan from the temporal bones was made later to determine the 3-D anatomy and experimental geometry. We present results from 3 animals. Pressure gain curves are remarkably smooth. They start at their lowest value (~ 5) at 190 Hz and rise to a maximum (~10 to 20) around 1.25 kHz. Then the curves show gradual fluctuations between 5 and 30. For two animals there is a broad minimum at ~ 30 kHz followed by an increase of ~ 20 dB. For the third animal the gain remained nearly constant above 6 kHz. The gains were similar to those in the recent report by Dong and Olson (J.Neurophysiol., 2006). For all animals, the pressure transfer function phase steadily decreased from +900 at 190 Hz to about -500o at 40 kHz. The frequency response of the piston component and the pressure gain exhibit both similarities and differences. The piston amplitude increases with frequency more slowly than the pressure gain. Then it follows the gross trend in pressure gain, but it shows fluctuations that are larger and sharper compared to those found in the gain. Above 30 kHz the amplitude rises to a maximum at about 35 kHz, and then drops off again. A gain dip at 5 kHz is reproduced in the piston amplitude of all three animals but the dip at 10 kHz is accompanied by a maximum in piston amplitude. The location of the peak and dips in the amplitude of the tilting components does not show that a smoothing effect of the gain could be inferred from a summing of the displacements caused by piston and tilting components. As a closing remark, more recent experiments show that the intracochlear pressure and stapes piston are relatively similar when measured simultaneously and with a more direct observation angle to the stapes; these methodological improvements reduce the need to hypothesize that non-piston components contribute to the transmission path

5.4

Mechanical excitation of complex stapes motion in guinea pigs

C. Breuninger[1], D. Sequeira[2], A. Huber[2], A. Eiber[1], Stuttgart; Germany[1], Zurich; Switzerland[2]

Objective: As observed and widely-accepted the natural vibration pattern of the stapes on acoustic stimulation reveals a complex motion pattern dependent on the frequency of excitation. Whereas for low frequencies the motion is predominant piston-like, significant rocking can be observed for higher frequencies. The cochlea fluid is mechanically exited by the piston like motion and two rotational movements along the short and long axis of the footplate. The rotational components produce no net volume flux of the cochlea fluid and therefore, the influence on the hearing sensation is still an open question. To investigate the response of the cochlea on complex motion of the stapes footplate, different vibration pattern on the stapes has been applied in anesthetized guinea pigs. Methods: A test rig to position the subject, an actuator and a laser Doppler vibrometer was build up using aluminum profiles. For adjustment of subject, actuator and laser micro manipulators were used. A three-axis piezoelectric actuator has been designed and coupled to the stapes head by a coupling rod of the surgically prepared guinea pig. For capturing the effective motion of the stapes 3D-Laser-Doppler vibrometry was applied. The excitation procedure to get cochlea response of arbitrary stapes motion consists of both an identification and a measurement phase to determine 1) the transducer behavior and 2) the electrophysiological measurements of the cochlea potentials on the desired piston motion. Transducer activation, spatial velocity of stapes and cochlea potentials are captured simultaneously by the data acquisition system for appropriate post-processing. Results: The task of driving arbitrary motion pattern yields a much higher complexity than classical one dimensional consideration. The load of the stapes structure to the transducer necessitates a particular control of transducer actuation to produce the desired motion patterns. The independently varied mechanical stimulation patterns reveal different intensities of cochlea response depending on the amount of piston and rocking like motion of the stapes.

5.5

The effects of complex stapes motion on the response of the cochlea in guinea pigs

D. Sequeira[1], C. Breuninger[2], A. Eiber[2], A. Huber[1], Zurich; Switzerland[1], Stuttgart; Germany[2]

Purpose: Studies into the vibration modes of the stapes in

response to acoustic stimulation of the normal ear have revealed a complex movement pattern of its footplate. These complex vibrations can be expressed as one translational displacement and two rotational movements around the long and short axes of the stapes. According to the classical theory of hearing, the rotational motions induce no volume displacement of cochlear fluid and, therefore, no cochlear activity (i.e. hearing sensation). It is the goal of this study to verify this hypothesis.

Material and Methods: The external and middle ear of anesthetized guinea pigs were surgically exteriorized, hereby, exposing the stapes superstructure. In turn, a custom-built, three-axis piezoelectric actuator, capable of eliciting any desired vibration mode, was coupled to the remaining stapes superstructure. When producing different movement patterns, electrophysiological measurements of the cochlear potentials were simultaneously recorded.

Results: Mechanical stimulation of the stapes according to the three elementary motions delivered three cochlear potentials of different amplitude. The greatest potential resulted from translational displacement.

Conclusion: The results of the present study show a cochlear excitation in all performed movement patterns of the stapes, including rotational movements. Hence, the prevailing hypothesis was not verified.

5.6

Canal obliquity and stapes velocity transfer function

T. Maetani[1], S. Puria[2], R. Goode[2], Toon; Japan[1], Stanford; USA[2]

Purpose: The goal of our experiments is to evaluate factors that affect upon the middle ear transfer function. For the better understanding of middle ear mechanics we need to know factors that affect upon the middle ear transfer function measured by a laser Doppler vibrometer. In this paper we tried to figure out the effects of dryness, the position of the probe tube microphone (PT mic) and the ear plug, aerated cochlear in preliminary experiments and focused on the effect of canal obliquity.

Material and Methods: Ten temporal bones were used. A laser Doppler vibrometer (HLV-1000) measured the stapes velocity (Vst). First, measurements were made with the natural EAC. After measurements with N-EAC, the bony canal was drilled and Vst with A-EAC was measured with the same bone. The sound stimulus for all measurements was a chirp swept over 200 logarithmically-spaced frequency points from 0.1 to 25 kHz. All measurements were performed using SYSid 6.5. This software program with a DSP-16+ processing board produces an output signal used to drive a sound source, and synchronously measures and averages the magnitude and phase angle of two input signals at each frequency.

Results: Dryness decreased the SVTF by 5 dB at low frequencies by leaving the specimen in a room with 30 % humidity for 6 hours. The position of PT mic significantly changed the SVTF at high frequencies. At 8 kHz 10 mm difference with PT mic position caused 20 dB elevations in SVTF magnitude. Aerated cochlear seemed to increase the SVTF by 5 to 15 dB at frequencies from 1 to 10 kHz (preliminary experiments) .The mean SVTF (Vst/Peac) with A-EAC was similar with previous report, and the difference between SVTF with N-EAC and with A-EAC were less than 5.2 dB in magnitude and less than 45 degrees in phase angle at frequencies between 0.1 and 15 kHz.

Conclusion: Significant difference between SVTF with N-EAC and A-EAC were not detectable. The most influential factor that affects upon SVTF at high frequencies was the position of the probe tube microphone

5.7

Fresh tympanic membrane perforations heal without significant loss of strength

M. von Unge[1], A. Rahman[1], JJ. Dirckx[2], M. Hultcrantz[1], Västerås; Sweden[1], Antwerp; Belgium[2]

Purpose: Assessment of the strength of the tympanic membrane recently after an acute perforation has healed and assessment of the scar structure. Background: In previous studies efforts have been made to enhance the healing process of tympanic membrane perforations. The strength of the healed perforation has been tested with moiré interferometry in gerbils, but in no other species.

Material and methods: A laser myringotomy was made on ten Sprague-Dawley rats and ten CBA mice, and strength assessments were made after two or four weeks with moiré interferometry for strength measurement. Light and electron microscopy were performed after measurements.

Results: Sprague-Dawley rats: the stress-strain curve of the rat tympanic membrane displays an "S"-shape. The mean peak displacement at pressure loads of + and of - 350 daPa did not differ significantly in the ears with healed perforations as compared to the untouched tympanic membranes. Morphological assays showed a five-fold increased thickness at the site of the perforation due to invaded fibroblasts and extra cellular matrix at 2 and 4 weeks post myringotomy. The scar formation was predominant on the middle ear side of the lamina propria. CBA mice: the moiré interferometry method was not easily applicable due to technical difficulties in preparing the specimen.

Conclusion: Moiré interferometry was successfully done in the rat, while not in mouse. The strength of the spontaneously healed tympanic membrane after myringotomy was not significantly impaired due to a relatively thick scar formation. Thus, a recently closed perforation will probably tolerate the challenge by pressure gradient in every day life. Myringoplasty surgery performed with fascia underlay appears to be well in accordance with the way nature heals a tympanic membrane perforation: fibrous tissue medial to the remnant of the lamina propria.

5.8

Boost of transmission at the pedicle of the incus in the chinchilla middle ear

MA. Ruggero[1], L. Robles[2], AN. Temchin[1], YH. Fan[1], H. Cai[1], Evanston; USA[1], Santiago; Chile[2]

We are re-examining ossicular vibrations in the middle ear of the living chinchilla, a species with a relatively narrow hearing bandwidth, similar to that of humans. This study was motivated by a review that disputed the commonly held notion that middle-ear vibrations restrict the bandwidth of hearing (Ruggero and

Temchin, P.N.A.S. USA 99: 13206-13210, 2002). The new measurements are facilitated by better stimulus and recording methodologies than were available when we conducted our initial study of the chinchilla middle ear (Ruggero et al., JASA 87: 1612-1629, 1990). The vibratory responses to tones of the long process of the incus just peripheral to the pedicle, the lenticular plate of the incus, and the head of the stapes were measured using a laser velocimeter and a wide-band acoustic-stimulus system. The velocity magnitude of stapes vibrations was relatively constant (~0.1 mm/s/Pa) up to 32 kHz and decreased at a rate of ~-20dB/oct at higher frequencies. Phase lag relative to pressure in the external ear canal increased approximately linearly, with a slope equivalent to a pure delay of 76 μs. Both the large bandwidth and the delay of the middle-ear responses appear to originate principally at the tympanic membrane, since they are present in the vibrations of the incus peripheral to its pedicle. These features, however, are refined by a wide peak in the magnitude of the transfer function across the incus pedicle, i.e., between the long process and the lenticular plate, which is accompanied by a large phase lag. The magnitude peak boosts vibrations by about 16 dB at 25 kHz, further flattening the magnitude middle-ear transfer function. The phase lag extends the range of constant delay to about 20 kHz. The vibration of the head of the stapes is similar to that of the incus lenticular plate. This implies that the pedicle of the incus provides more flexibility to the ossicular chain than the incudo-stapedial joint, as previously suggested (Funnell et al., JARO 6: 9-18, 2005). The present results support the contention that the chinchilla middle ear behaves as a wide-band pressure transformer which transmits acoustic signals into the cochlea even at frequencies exceeding the cut-off of hearing (Ruggero and Temchin, op. cit.).

5.9

Equivalent noise levels generated by the rotating burr on the ossicular chain as measured by Laser Doppler Vibrometry: A temporal bone study

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Background: Inadvertent drilling on the ossicular chain, usually in the region of the short process of the incus, has been regarded as one of the causes of a sensorineural hearing loss that may follow tympanomastoid surgery. Post-operative high frequency hearing loss is more often observed than low frequency hearing loss. It is therefore speculated that the hearing loss is caused by vibration of the ossicular chain that resembles acoustic noise trauma. It is generally considered that using a large cutting burr is more likely to cause damage than a small diamond one; although the mechanism of drill induced hearing loss is poorly understood. Laser Doppler Vibromatory allows a no mass analysis so necessary for the measurement of ossicular chain micromovement.

Aim: The aim was to investigate the equivalent noise level, and its frequency characteristics generated by drilling onto the short process of the incus.

Methods and Materials: Five fresh cadaver temporal bones were used. The stapes displacement was measured using Laser Doppler Vibrometry during drilling episodes. The vibratatory stimulus for each episode was achieved by engaging the burr on the posterolateral surface of the short process of the incus. Diamond and cutting burrs with different diameters (1 mm, 2.3 mm and 3.1 mm) were used for the study. The effect of drilling was compared with the acoustic signal generated stapes displacement and the equivalent noise level calculated. Results: The equivalent noise levels generated by drilling on the incus ranged from 93 - 124 dB SPL. For a 1 mm cutting burr, the maximum noise level was 107 dB SPL, whilst a 2.3 mm cutting burr produced a maximum noise level of 124 dB SPL. Diamond burrs generally generated less equivalent noise level than their cutting counterparts, with a 2.3 mm diamond burr generating a maximum equivalent noise level of 102 dB SPL. With a cutting burr, the energy of equivalent noise increased at the higher end of its frequency spectrum, a 2.3 mm cutting burr producing an equivalent noise level of 104 dB SPL at 1 kHz, but 124 dB SPL at 8 kHz. In contrast, the same sized diamond burr produced 95 dB at 1 kHz and 99 dB at 8 KHz respectively.

Conclusion: This study suggests that inadvertent burring on the ossicular chain can produce vibratory force that would be analogous with noise levels known to produce hearing loss. For the same type of burr, the larger the diameter the greater the vibratory force, and for the same size of burr, the cutting more than the diamond burr. The cutting burr produces more high frequency than lower frequency vibratory energy.

6.2

Storage of the incus in the mastoid bowl for use as a columella in staged tympanoplasty

K. Gyo[1], T. Maetani[2], N. Hato[1], Y. Shinomori[2], Matsuyama[1], Toon[2]; Japan

Purpose: To evaluate whether the incus of the cholesteatomatous ear preserved in the mastoid bowl during the first stage of planned two-stage tympanoplasty can tolerate long-term implantation and be used in ossicular reconstruction during the second stage.

Methods: The study group included 24 patients who underwent staged tympanoplasty for the treatment of middle ear cholesteatoma. At the first stage, after removing the incus to eradicate the middle ear disease, it was returned to the mastoid bowl and stored there until use at the second stage. The average interval between the two stages was 8.3 months (range 6-12 months).

Results: The incus was identified in all cases at the second stage: ten incudes were found to be covered with a thin mucosa layer, 12 were buried in fibrous or granulation tissue, and two were joined to the surrounding bone. Residual cholesteatoma was found in six ears, either in the attic (three ears) or tympanic sinus (three ears). It never occurred in the mastoid bowl where the incus had been preserved. In 19 cases, the incus was available as a short columella for ossicular reconstruction. The remaining five cases were reconstructed using a hydroxyapatite ossicle as a long columella, since the stapes superstructure was missing at the second stage. In one case, the stored incus underwent remarkable absorption between stages.

Conclusion: Preservation of the incus in the mastoid bowl is an effective option in planned two-stage tympanoplasty, when the incus is considered useful for ossicular reconstruction at the second stage.

6.3

Incusinterposition: surgical highlights and audiological results

Ch. Röösli, A. Luiz de Ataide, Ch. Schlegel-Wagner, T. E. Linder, Lucerne; Switzerland

Objective: To describe the technique used for incus interposition with the autologous and a Titanium incus and evaluate the 1-year postoperative functional results.
Study design: Retrospective study.
Setting: Tertiary referral center.
Patients: Sixty consecutive patients who underwent incus interposition between October 2001 and January 2004 were enrolled. The surgeries were either primary interventions, revision surgeries or planned staged ossiculoplasties in closed or open cavities.
Surgery: In patients with an intact malleus handle and stapes suprastructure an incus interposition was performed using either the patient's own ossicle or a Titanium prosthesis.
Main Outcome measures: Pre- and postoperative air and bone-conduction thresholds and air-bone gaps for pure-tone averages of three and four frequencies and for single frequencies were analyzed.
Results: Ossiculoplasties were performed using autologous ossicles (34 patients) and Titanium prosthesis (26 patients). Mean postoperative air-bone-gap improved from 26dB to 15dB for the frequencies of 0.5kHz to 2kHz and from 25dB to 17dB for the frequencies of 0.5kHz to 4kHz. The largest improvement could be reached in the lower and middle frequencies, whereas smallest improvements were achieved at 4kHz. A favourable postoperative air-bone-gap of 20dB or less was achieved in 91% of patients using autologous ossicle and in 65% of patients using titanium prosthesis. There were no statistically significant differences between open or closed cavities, nor in cases after removal of the malleus head.
Conclusions: Sculpted autologous incus interposition provided the maximum hearing success, however the audiological results of the new Titanium prosthesis did not differ significantly ($p = 0.11$). Further studies may verify why the closure of the air-bone-gap at 4kHz was less successful than in lower frequencies.

6.4

Tympanic membrane blunting: prevention and treatment

TL. Eby, Birmingham; USA

Anterior tympanic membrane blunting results in persistent conductive hearing loss and patient dissatisfaction despite successful closure of a perforation. Tympanic membrane compliance and efficiency in sound transmission is impaired. In extreme cases the entire tympanic membrane may lateralize giving a false fundus with maximal conductive loss. The causes of blunting may be both surgical technique and poor wound healing. We describe our techniques for prevention of blunting which include adequate support and anchoring of the fascial graft in an underlay technique and the use of thin split thickness skin grafts. Post operative follow up in clinic to monitor healing is important. Examples of the techniques and results are presented.

6.5

Preservation of the intact ossicular chain in cholesteatoma surgery

J. Hamilton, Gloucester; UK

Aim: This study was undertaken to assess the feasibility of preserving the intact ossicular chain when undertaking cholesteatoma surgery and to assess the ensuing audiological and clinical outcomes

Method: Patients were eligible for this study if at operation for cholesteatoma surgery the ossicular chain in the operated ear was confirmed to be continuous and mobile.
Patients were enrolled for this study until December 2004.
The main outcome measures were the air-bone gap in the operated ear, and whether audiological parameters satisfied the Belfast criteria.

Results: 85 patients with intact ossicular chains underwent cholesteatoma surgery during the study period.
71 patients completed surgery with intact ossicular chains.
When the ossicular chain remained intact, the mean air-bone gap one year after the completion of surgery was 12.5 dB HL. The Belfast criteria were satisfied in 82% of cases.
If the ossicular chain was dismantled and reconstructed, the median air-bone gap one year after surgery was 19.7 dB HL. The Belfast criteria were satisfied in 55% cases.
Discussion: Data presented at the 2nd Middle ear mechanics symposium in 1999 indicated that hearing outcomes after cholesteatoma surgery were best with an intact ossicular chain.

This study was undertaken to assess the outcomes if the surgical technique minimised the occasions when a continuous chain was dismantled.

The study indicates that in most cases the intact ossicular chain can be preserved and that the hearing results are improved as a result.

6.6

Tympanoplasty today – an analysysis of 11000 cases of reconstructive middle ear surgery – the Würzburg experience

J. Müller, F. Schön, S. Brill, J. Helms, R. Hagen, Würzburg; Germany

Nowadays middle ear surgery is not only done to treat mastoiditis and to prevent its complications, which are highly dangerous. Middle ear surgery is also done to restore the hearing. Ojala summed up the situation in the seventies when he stated that "hearing after tympanoplasty usually does not improve (and in some cases even deteriorates)".

Since Wullstein (Würzburg) discribed the basic principles of tympanoplasty in the early 50ties, many other otologists made additional contributions to our current knowledge of tympanoplasty. The aims of tympanoplasty have been and still are:
- the elimination of the pathological changes
- to create stable conditions and easy access for postoperative care
- to reconstruct the sound conduction mechanism.

Numerous grafting materials have been recommended for the closure of tympanic membrane perforations. This paper evaluates three different grafting materials for the reconstruction of the tympanic membrane:
- Pericondrium
- Cartilage
- Perichondrium-Cartilage Composite Graft

The study is based on a computerized documentation system called "Würzburger Ohrbogen". This system includes now more than 11000 patient's records. The database comprises information on surgical details (324 items) and patients follow up. All patients included in the study had a minimum follow up of 6 months.
The aim of the study was to analyse the audiological results of different grafting materials, which were combined with ossicular chain reconstruction.

In general, the audiological results achieved in ears which needed a tympanoplasty type I or III showed postoperatively for 80 % of the patients an improved hearing compared to preoperatively.
The best hearing results were achieved in those ears in which primary tympanoplasty type I was performed without ossicular chain reconstruction (type I tympanoplasty). The grafting materials we used (perichondrium, cartilage palisades, perichondriumcartilage composit graft (PCCG)) showed 6 months postoperative a similar air bone gap. The audiograms were measured for the frequencies from 0.5 kHz to 8 kHz. Hearing results were best at 2 kHz.

As expected, those patiens who requiered type III TORP tympanoplasty enjoyed less hearing recovery than those who required a type I tympanoplasty or a PORP.

Perichondrium and the cartilage techniques led to simular results.

It should not be unmentioned that repreferations occured. The perforation closure rate in type III tympanoplasties was 92.3%, the total repreferation rate was 7.7 %.

Based on temporal bone studies using a laser doppler vibrometer also the influence and the audiological quality of different middle ear protheses is discussed. The results of the temporal bone study as well as the initial clinical findings using a new light titanium (n=396) prostheses are discussed. Not surprisingly the combination or different graft materials and different protheses led to similar clinical results except in type III TORP tympanoplasty. In these type of tympanoplasty with a reconstruction of the ossicular chain between stapes footplate and reconstructed eardrum significant better results were obtained when using cartilage.
Based on our data we can conclude that tympanoplasty nowadays is able to improve the hearing.

6.7
The efficacy of one-stage tympanoplasty with mastoid obliteration and a tympanoplasty by an endaural approach using ceramic prosthesis
KE. Hayashi, AT. Shinkawa, Hadano; Japan

Purpose: To confirm the efficacy of one-stage tympanoplasty with mastoid obligation and a tymapanoplasty by an endaural approach using ceramic prosthesis

Materials and Methods: Our surgical procedure for middle ear was performed on 163 patients with cholesteatoma and 545 patients with chronic otitis media in shinkawa clinic between Jun 2001 and December 2005. The operative method was classified into two groups. We use one-stage tympanoplasty with mastoid obliteration, a canal wall down procedure for chronic otitis media with cholesteatoma and chronic otomastoiditis. On the other hand, we use a tympanoplasty by an endaural approach for chronic otitis media without chronic otomastoiditis. The ossicular chain was reconstructed using the ceramic ossicular prosthesis (P-type and T-type). We performed modified Type III tympanoplasty using the P-type ceramic when the superstructure of the stapes could be utilized, while we performed modified Type IV tympanoplasty using the T-type ceramic when the superstructure of the stapes could not be used.

Results: In chronic otitis media with cholesteatoma and chronic otomastoiditis, the success rate of modified Type III tympanoplasty using ceramic P type was 77.8%, on the contrary that of modified Type IV tympanoplasty using ceramic T type was 70.6%. In chronic otitis media without chronic otomastoiditis, the success rate of modified Type III tympanoplasty using ceramic P-Type was 69.8%, while that of modified Type IV tympanoplasty using ceramic T was 69.1%.

Conclusion: Our results show that there are no significant differences of success rate between these two procedures. Therefore, we confirmed that the use of ceramic implant was satisfactory for both one-stage tympanoplasty with mastoid obliteration and a tympanoplasty by an endaural approach.

7.1
Keynote Lecture

The development and utility of quantitative models of middle-ear function
JJ. Rosowski, Boston; USA

Purpose: Middle-ear models are used to elucidate our understanding of the relationships between middle-ear structure and function as well as to make predictions of the effects of alterations in structure on function. A review of models in the literature reveals a range of model complexities, from simple heuristic models with a few parameters, to complex finite-element models with large numbers of parameters.

Materials & Methods: The talk will address the utility and the limitations of the different classes of middle-ear models via the discussion of illustrative examples of different model types ranging from simple lumped models through distributed element and finite-element models.

Results & Discussion: Models of hearing function in normal and pathological ears will be discussed: including heuristic models of middle- ear transformer function, lumped and distributed models of TM perforation and distributed and finite-element models of normal TM function. The discussion will include: What kinds of new data are needed to better test models of middle-ear function? and should model predictions, by themselves, be used to make clinical decisions, or should they only be used to direct further research? [Supported by NIDCD]

7.2
Conceptual design of the human middle ear
H. Hudde, Bochum; Germany

If the functionality of the middle is considered mostly the ability of effectively transmitting sound energy from the air in the ear

canal to the fluids in the inner ear is examined. However, to assess the ""quality"" of the middle ear it is necessary to consider also other aspects than the transmission of sound. The human middle ear turns out to provide a larger auditory frequency range, lower general parameter sensitivity and better protection of the inner ear than a columella ear. The favourable properties are best understood by regarding the vibrations of the ossicular chain under different conditions and for different kinds of excitation. The vibrations are provided as animations computed by means of a generalised circuit model. Simulations have an invaluable advantage compared with experiments: conditions can be altered very easily and exactly. Changing conditions can give much deeper insight than merely investigating the normal behaviour. To discover the particular features, animations of middle ear vibrations have been calculated for the normal chain and for impairments introduced by altered positions and by stiffening compliant elements such as joints and ligaments. Using the generalised circuit model translational and rotational components of the elastic elements can be varied independently of each other. The different conditions are examined for acoustic stimulation by an eardrum pressure and for mechanic excitation by shaking the complete tympanic cavity in three orthogonal directions. All the visualisations taken together reveal a remarkable conceptual design of the human middle ear: It is known since long that the incudomalleal joint acts as an element protecting the inner ear against external forces. But a robust overload protector requires fairly strong bony material. Therefore the incudomalleal joint is necessarily encased by heavy masses which tend to worsen the sound transmission. In the talk it will be shown that the design of the human middle ear does not only circumvent a decrease in transmission at too low frequencies, but even takes advantage from the mass centre formed by the malleus head and incus body. The surprising features are achieved by the particular shape of the ossicular chain in combination with a favourable design of the elastic elements involved.

7.3

Acoustic-structural coupled finite element analysis for sound transmission in human ear – middle ear transfer function

RZ. Gan[1], T. Cheng[1], MW. Wood[2], Norman[1], Oklahoma City[2]; USA

A 3-dimensional finite element (FE) model of human ear with accurate structural geometry of the external ear canal and middle ear, including tympanic membrane, ossicles, suspensory ligaments, and middle ear cavity, has been recently published by our group. The model has been built with fluid (air) - structural interfaces among all the moving surfaces for coupled analysis from the ear canal through tympanic membrane (TM) to middle ear cavity. In this paper, the coupled FE analysis was employed to derive acoustic-mechanical transmission from the air-filled canal to the stapes footplate in normal and pathological ears. The structural alterations such as perforations of the TM caused by trauma or chronic otitis media were created in the model at different locations with various sizes for acoustic-structural coupled FE analysis. In the meantime, perforations of the TM were generated in human cadaver ears or temporal bones. Two laser Doppler interferometers were used to measure simultaneously the transfer function of the middle ear in terms of the relationship between vibrations at the TM and stapes footplate. The FE model-derived results on transfer functions of the middle ear under normal and TM perforation conditions are very similar to the data measured from temporal bones across frequency range of 200 to 8k Hz. The FE model provides precise predictions on the effect of perforation location and size on middle ear transfer function. This study indicates that our FE model can serve as an excellent analytic tool for investigating middle ear structure-function relationship in normal and pathological ears with visualization of structural variation and multi-field mechanics analysis

7.4

Effects of middle ear suspensory ligaments on acoustic-mechanical transmission in human ear

RZ. Gan[1], T. Cheng[1], D. Nakmali[2], MW. Wood[2], Norman[1], Oklahoma City[2]; USA

The middle ear including tympanic membrane (or eardrum) and three ossicular bones (i.e., malleus, incus and stapes) constitutes a mechanical system for sound transmission from the external ear canal to cochlea. Three ossicles are suspended in an air-filled middle ear cavity by suspensory ligaments/muscle tendons and coupled to the eardrum by manubrium of the malleus. To describe meddle ear biomechanics, it is necessary to understand mechanical properties of the suspensory ligaments and the effects of those tissues on acoustic-mechanical transmission through the ear. In this paper, we report bioengineering systems approach on ligaments function measurement and mechanical testing of human cadaver ears. Two laser Doppler vibrometers were used to measure simultaneously the movements of stapes footplate and eardrum in temporal bones across the auditory frequency range. After control study with intact ossicles, middle ear suspensory ligaments and tendons, such as superior mallear ligament, posterior incudal ligament, stapedial tendon, and tensor tympani muscle tendon, were sectioned sequentially and displacements of the stapes footplate and eardrum were measured repeatedly for every section. In the meantime, the mechanical properties of stapedial and tensor tympani muscle tendons were measured in micro-tensile material testing system. A 3-D finite element (FE) model of human ear with accurate anatomic structure was then used for acoustic-mechanical analysis. The model-derived eardrum (umbo) and stapes footplate vibrations as the input sound was applied at the canal were compared with the results obtained from laser measurements in temporal bones. Our results show that the effects of ligaments on transfer function of the ear are frequency sensitive and vary with individual ligaments. The FE model demonstrates that a bioengineering systems approach provides a better understanding of ear biomechanics.

7.5

A new model for training in tympanoplasty

G. Hofmann, M. Bornitz, N. Lasurashvili, H. Seidler, T. Zahnert, Dresden; Germany

Functional simulation of middle-ear reconstructions is a desired ambition of otosurgeons. Recently we have introduced a new middle-ear experimental model. It provides a reliable feedback acoustic information, reflecting accurately the functional quality of reconstruction results of a middle-ear ossicular chain. In proposed model the tympanic membrane and ossicular chain have to be recovered reaching a proper sound transmission to the artificial inner-ear receptor. The received signal is converted into the acoustic information and is consecutively applied to the

headphone. The reconstruction results can be estimated therefore online while immediately be optimized by a surgeon or a trainee.

7.6

Evaluation of laser vibrometry as diagnostic utility by means of a simulation model of the middle ear

M. Bornitz[1], T. Zahnert[1], HJ. Hardtke[2], Dresden; Germany[1],[2]

Laser Doppler Vibrometry has already been used in clinical studies to investigate its potential as a diagnostic utility. It is aimed to distinguish the different pathologies of conductive hearing loss and to evaluate the quality of reconstructive middle ear surgery. The purpose of this work is to simulate the different pathologies and their influence on the transfer function in order to show what is possible to distinguish in clinical measurements. We used a Finite Element Model of the middle ear for the investigations. Calculations were performed accordingly to the clinical measurements to get comparable results. The displacement of the umbo was calculated with applied sound pressure at the tympanic membrane. Harmonic analysis in the frequency range from 200 to 5000 Hz was used to calculate the transfer function. Calculations were done for intact middle ears with different sets of parameters to account for the individual variations and for the following pathologies: malleus and incus fixation, chain interruption, stiffening of annular ligament (otosclerosis), imperfect prosthesis reconstruction. The magnitude of the transfer functions varies by about 10dB due to the individual variations. Stiffening of the annular ligament leads to a reduced magnitude in the low frequency range and a change of the overall slope of the transfer function. Ossicular chain interruption gives a clear resonance peak below 1000 Hz. Imperfect prosthesis coupling produced only minor changes in the transfer function as long as the prosthesis is not completely dislocated. Malleus and incus fixation reduces the magnitude of the transfer function in the whole frequency range if bone like fixation is assumed. Results of the simulations are in good agreement with some clinical studies using the laser vibrometry. Stiffening of the annular ligament lead to the same characteristics in the transfer function as measurements on otosclerotic ears. The same holds for ossicular chain interruption. Both pathologies can be clearly distinguished from normal ears by means of the calculated transfer functions. Malleus and incus fixation can only be surely detected if the fixation is nearly rigid.

7.7

Imaging, physiology and biomechanics of the malleus-incus complex

JH. Sim, S. Puria, CR. Steele, Stanford; USA

Purpose: The goal of this study is to establish the biomechanical model of the malleus-incus complex (MIC) based on specific anatomical features of individual ears. Characterization of the malleus-incus complex requires morphological parameters for the bones and soft tissue attachments and their associated material properties. We characterize the isolated malleus-incus complex by combining three-dimensional dynamical measurements and high-resolution microCT based morphology within a biomechanical model features.

Material/Methods: To reduce the complexity of middle ear function and isolate the malleus-incus complex, the eardrum and stapes are dissected by a surgical laser. Without an ear drum, the isolated malleus-incus complex was driven by an electromagnetic field between a tiny magnet attached to the umbo and the coil around the tympanic annulus. The electromagnetic forces are calculated with the dimensional information obtained from microCT scan. Three-dimensional motions of the isolated malleus-incus complex driven by magnet-coil system are calculated from measurement with laser vibrometer. Velocities of several points on the isolated malleus-incus complex, which is attached to two stacked goniometers, are measured from several different angles. Anatomical information of the malleus-incus complex, which is important due to large individual differences, was obtained using high resolution microCT imaging methods. This anatomical information includes typical ligament position, geometric feature of the incudo-malleolar joint (IMJ), and mass distribution of each bone. The described 3D motions were used to estimate parameter values in our anatomically based structural model. In the mathematical model, ligaments were modeled as linear springs and dashpots, and the incudo-malleolar joint was approximated by plane Poiseuille flow. Parameter values of the mathematical model were obtained by Levenberg-Marquardt method applying measured 3D motion to the model.

Results/Conclusion: The Non-destructive imaging method of MicroCT was used to characterize three dimensional features of soft tissues and mass distribution of each bone in the malleus-incus complex. Dimensions and orientations of suspensory cells show significant differences in different temporal bone preparations. Such individual differences in the anatomical features of the middle ear require accurate determination of anatomical information for each specimen. The incudo-malleolar joint has a shape of two orthogonal saddles with maximum gap of 275 μm in the anterior-posterior direction and a minimum gap of 70 μm in the lateral-medial direction. The 3-D motion of the malleus-incus complex driven by magnet-coil system was observed with slippage at the incudo-malleolar joint. For frequencies below 1.5 kHz, the motion of the isolated malleus-incus complex could be represented by a simple rotation about a neutral axis showing a small amount of slippage at the incudo-malleolar joint. At higher frequencies, the malleus-incus complex showed complicated motions with bigger slippage at the joint. Parameter values in our anatomically based mathematical model were obtained with repeated measurements removing elastic components from the malleus-incus complex one by one. The parameter values were consistent with those reported in previous studies. However, the stiffnesses correspond to lower volume fractions of collagen or lower elastic modulus than expected.

7.8

Basilar membrane displacement with opened and occluded oval window and bone conduction

F. Böhnke[1], A. Arnold[2], T. Fawzy[1], Munich; Germany[1], Berne; Switzerland[2]

Material: During stapedectomy the stapes footplate is removed completely. With the opened oval window the hearing thresholds with bone conducted stimulation show a constant increase in all patients. This clinical finding is caused by the changes of the hydromechanical sytem, which is sealed at the oval window in the physiological and otosclerotic case.

Methods: To further study this effect we used a three dimensional Finite Element (FE) Model to evaluate the different case numerically. The lymph is idealized by a nearly incompressible and inviscid fluid with the mechanical parameters of water. The ambient bone is represented by fixed and immovable nodes as the normal boundary condition, but these may be loaded to implement the external pressure acting during bone conduction. There are four interfaces between movable elastic structures. These are at the inner areas of the stapes footplate and the round window and the upper and lower areas of the basilar membrane (BM). Further foramina like an open aqueductus cochlearis or the saccus endolymphaticus are not considered for the present. With these assumptions we are able to verify experimental findings and furthermore simulate states, which are difficult to make up.

Results: In all cases the level of stimulation was 70 dB(SPL) equivalent to 63.2 mPa. With a normal elastic round window and a fixed footplate the maximum BM displacement is about 0.014 nm, which will be the reference for the results with bone conduction because it is almost independent from the frequency of stimulation. In case of a completely removed footplate the maximum BM displacement increases between 750 Hz and 4 kHz and is maximal for 1500 Hz (0.04 nm or 9 dB). The reduction of the foramen size, which might represent the piston hole during stapedotomy causes a decrease of the maximum BM displacement by 2 dB. In conclusion the results confirm actual clinical findings during stapes surgery. Because of the flexibility of the FE Model further settings which are difficult to realize in experiments can be studied in the future.

7.9
Linearity of the middle ear before and after reconstruction
O. Majdalawieh, M. Bance, R. van Wijhe, Halifax; Canada

Purpose: To determine if the human middle ear is linear both before and after reconstruction. This is important for hearing aid use at high presentation levels, and also determines if reconstruction changes linearity.

Methods: Five fresh human temporal bones were used. The stapes vibration amplitudes were measured in response to increasing amplitudes of sound stimulation at 70, 90 and 110dB SPL. This was perfomed at several discrete frequencies. The incus was then removed, and a PORP prosthesis placed. The experiments were repeated

Results: The responses both before and after reconstruction were superimposable once corrected for presentation sound pressure level.

Conclusions: The human middle ear is linear within the tested range in both the intact ear and the reconstructed ear.

8.1
Mechanical problems in human hearing
A. Eiber, C. Breuninger, Stuttgart; Germany

A description of the hearing process is given using three-dimensional mechanical models. By means of simulation normal, pathological and reconstructed situations can be investigated. The development of new concepts and prototypes as well as the optimization and the way of insertion of passive and active implants is facilitated by carrying out virtual tests. Mechanical models of spatial structures of the middle ear and its adjacent regions are established by applying multibody systems and finite element modeling approach. In particular, the nonlinear behavior of the elements is taken into account. For the determination of parameters such as coupling parameters in reconstructed ears, measurements using laser Doppler vibrometry (LDV) were carried out. The governing differential equations of motion allow the investigation of transient and steady state behavior by time integration and frequency domain methods. Optimization methods can be applied for determination of design parameters such as coupling stiffness and damping, the characteristics of actuator, the position of attachment and direction of actuation. Mechanical models enable non-invasive interpretation of dynamical behavior based on measurements such as LDV from umbo or multifrequency tympanometry. It is shown: The transfer behavior is depending on static pressures in the ear canal, tympanic cavity or cochlea. For reconstructed ears, the coupling conditions are governing the sound transfer substantially. Due to restricted coupling forces the excitation of inner ear is limited and the sound transfer gets distorted. Other sources of distortion are nonlinear coupling mechanisms. In reconstructions with active implants, the actuator excites the microphone whereby feedback effects may occur.

8.2
The round window approach for MED-EL VSB in difficult-to-treat middle ear problems
V. Colletti, M. Carner, L. Colletti, L. Sacchetto, Verona; Italy

The present criteria for the Vibrant Med-El Soundbridge (VMSB) device limits its application to patients with sensorineural hearing loss (SNHL) and normal middle ear function. We have extended the indications of the VMSB to include patients with ossicular chain defects and implanted the floating mass transducer (FMT) onto the round window (RW) membrane. The very good preliminary results of this new approach observed in five patients (Colletti et al, 2005) prompted us to extend the experience to another seven patients for a total of 12 patients, all with severe mixed hearing loss. Their age spanned 1 - 74 years. Ten patients had been unsuccessfully operated on ossiculoplasty several times for ossicular chain defects, related to chronic otitis media in nine patients and external and middle ear malformations in one subject; 1 patient with SNHL had the VMSB crimped on the incus without hearing gain, and one 1-year-old child suffering from Goldenhar syndrome had external and middle ear malformations. A classic transmastoid approach with posterior tympanotomy was used in eleven patients, and a transcanal approach was utilized in one patient. In all patients a reshaping of the round window area for fitting the transducer was performed. The FMT was placed onto the round window membrane and covered with temporalis fascia and fibrin glue. The receiver/stimulator was placed at the level of the squama temporalis. No intra- or postoperative complications were observed and all patients were discharged 1-3 days after surgery. Short term test results from adult patients indicate dramatic improvements in pure tone threshold and speech understanding with outcomes very similar to stapes surgery. In adults the sum of the mean PTA (0,5-4 kHz) was 76.67 (SD=+/-4.7) pre-operatively and 20.69 (SD=+/-6.8) dBHL, 12 months post-operatively ($p<0.01$). The sum of mean percentage of bi-syllabic words was 6.5 (SD=+/-3.4) before surgery and 89.4 (SD=+/-8.1), 12 months post-operation ($p<0.01$). No short term

complications have been observed so far. Pre- and post-op. ABR testing indicated remarkable improvements in threshold in the 1-year-old child. No complications have been observed so far. The experience gained by this preliminary study shows that the VMSB with the FMT placed on the RW has new indications that can be summarized as follows : 1- bilateral conductive mixed hearing loss " resistent " to multiple middle ear reconstructive procedures, 2- external and middle ear malformations, 3- patients with sensorineural hearing loss obtaining limited benefit from MEI. Colletti V. et al .: Round window stimulation with the floating mass transducer: a new approach for surgical failures of mixed hearing losses. Proceedings of the XVIII IFOS World Congress - Rome 25-30 June, 2005 MEMRO 2006

8.3

The transcanal approach for the Vibrant Soundbridge: the experience of the clinic in Pisa

L. Bruschini, Pisa; Italy

Introduction: The Vibrant Soundbridge (VSB) is a middle ear implant for the treatment of the sensorineural hearing loss, for patients who cannot benefit from conventional hearing aids. The standard approach for VSB implantation icludes a postauricular S-shaped incision, mastoidectomy with posterior timpanotomy, the fixation of the implant to the temporal bone, and crimping of the vibrator on the incus through the posterior timpanotomy.

Objectives: The goal of this presentation is to suggest a minimal surgical procedure to place the VSB.

Methods: We placed the VSB in four patients adapting a minimal postauricolar S-shaped incision. The vibrator was crimped on the incus through a transcanal approach. A small channel in the external wall was drilled in order to position the cable.

Results: All patients were tested following a standard evaluation protocol. The preliminary results are described and discussed for each single case.

Conclusions: The possibility of the transcanal approach for the VSB can reduce the risk of facial nerve damage if special care is taken on the channel for the cable. Moreover, the technique may reduce the time needed to perform the surgery and reduce potential flap complications being a good cosmetic solution at the same time.

8.4

Vibrant Soundbridge clinical investigations: expanding indications for use

JM. Opie[1], M. Huetter[1], P. Grasso[1], S. Labassi[1], N. Giarbini[1], N. Dillier[2], A. Huber[2], Innsbruck; Austria[1], Zurich; Switzerland[2]

Purpose/Material: The Vibrant Soundbridge is a partially implantable "direct-drive" hearing system for the treatment of hearing loss and is currently indicated for use in adults who have mild-to-severe sensorineural hearing loss. Recently, the device has been applied to persons with mixed and conductive hearing losses to provide amplification to residual sensorineural hearing. In order to appropriately place the device in disordered and malformed ears, the manner and/or location of placement of the device is altered, and, in some cases, the device is used in conjunction with commercially available, passive middle ear prostheses. The objective of these studies is to evaluate expanding indications for use of the Vibrant Soundbridge to include persons with conductive and mixed hearing losses.

Methods: Subjects were implanted with the Vibrant Soundbridge implantable hearing aid, using either the Vibroplasty or Round Window Vibroplasty surgical technique. A single-subjects, repeated measures design is used to evaluate the safety and efficacy of the Vibrant Soundbridge in persons with conductive and mixed hearing losses.

Results: An overview of the study and its procedures, as well as preliminary results, will be presented.

8.5

Bypassing insufficient sound transfer in the chronically disabled middle ear by an active/passive prosthesis

K.-B. Hüttenbrink[1], TH. Zahnert[2], M. Bornitz[2], G. Hofmann[2], Cologne[1], Dresden[2]; Germany

In many patients with chronic middle ear diseases, like recurrent cholesteatoma, persistent tubal dysfunction etc., modern surgical techniques often result in an elimination of disease with a dry, small cavity, but even repetitive tympanoplasty cannot restore a social hearing. Implantable hearing aids promise a new alternative for these patients. Contrary to SNHL-patients with their concerns on ear-surgery, this group of patients often agrees to the proposal of a tympanoplasty for an improved hearing, due to their experience with previous surgeries. Furthermore, their regular hair-cell function promises a nearly-normal aided hearing.

The idea of a composite middle ear implant, which acts as a passive prosthesis in cases of adequate air conduction, but which will stimulate the cochlea by an active vibration in case of a chronically disabled middle ear, is obvious. Yet previous concepts had to be disregarded mostly due to technical reasons. We designed a new type of implant, merging our concepts of passive prosthesis design, which integrates the reliable Vibrant Soundbridge transducer in a titanium holder for a Columella-reconstruction.

Our concept promises a surgically easy procedure similar to a normal tympanoplasty. Temporal bone experiments demonstrate the acoustical efficiency of this composite columellar implant.

9.2

Invited Paper

Coupling problems in middle ear reconstruction

T. Zahnert, Dresden; Germany

The normal and reconstructed middle ear can be considered as a mechanical vibrating system. After the implementation of tympanoplasty as a standardized surgical technique various reconstruction techniques and implants were suggested for the reconstruction of the tympanic membrane and the ossicular chain. Laser-Doppler-vibrometry and model calculations have given new insight into the vibration modes of the normal and reconstructed middle ear during the recent years. Nowadays it can be

concluded, that not only material properties of implants but also coupling factors have an important influence on good hearing results. We investigated coupling factors between tympanic membrane and the surrounding bone, between the tympanic membrane and middle ear implants and between the prosthesis and the ossicular chain using model calculations and temporal bone experiments. The quality of the tympanic membrane, which can be considered as the "motor of the middle ear", has the most important impact on the sound transfer to the inner ear. Ventilation and mucosa problems can damp the tympanic membrane vibrations as well as the reconstruction techniques or the mechanical properties of transplants. The coupling of the tympanic membrane to either the surrounding bone or the cartilage transplants has an influence on the stiffness. The contact of the tympanic membrane to the malleus handle is of importance in order to allow good sound conduction to middle ear prostheses in the high frequency range. Furthermore the contact of prostheses to the stapes head or the footplate may influence hearing results. In our investigations the angle of prostheses towards the tympanic membrane and the stiffness of coupling plays an important role. Concerning the angle it is of importance to distinguish between the x and y - direction. An absolutely stiff contact between malleus and stapes can reduce the sound transfer and increase the risk of prosthesis dislocation or even damage of the annular ligament. Even nowadays modern middle ear reconstructions can only simulate the simple function of a columella. In future it may be important to invent middle ear implants which will be able to fulfill both required middle ear functions - the sound transfer and the compensation of atmospheric pressure changes. It can be assumed that hearing results may improve due to an unstressed coupling of middle ear prostheses by taking the above mentioned techniques and findings into consideration.

9.3

Induction of bone formation by titanium implants coated with immobilized recombinant human bone morphogenetic protein-2 in the rabbits petrous bone

A. Neumann[1], M. Chatzinikolaidou[2], C. Unkel[1], S. Dazert[3], HP. Jennissen[2], K. Jahnke[1], Duisburg-Essen[1,2], Bochum[3]; Germany

Purpose: Bone morphogentic proteins (BMPs) belong to the group of transforming growth factor (TGF-β) proteins and were shown to have numerous biological effects of which the osteoinductive ability is the most outstanding. By means of surface modification it has recently become possible to immobilize recombinant human (rh)BMP-2 on implant surfaces. As only few publications deal with rhBMP-2 effects in otology, the present study aims to evaluate both BMP effects and BMP-"coating" of titanium implants in the woven petrous bone.

Materials and methods: A total of 20 titanium cylindrical dumbbell shaped implants were manufactured containing equivalent composites as used for ossicular replacement prothesis. Subsequent to creating ultrahydrophilic, bioadhesiv surfaces, one half of the implants was used for immobilization of rhBMP-2. In 10 rabbits one titanium sample each was implanted in both tympanic bullae comparing the groups of immobilized rhBMP-2 vs. rhBMP-2-free and immobilized vs. soluble rhBMP-2. The formation of new bone in the gap healing model was observed by microradiographic and histomorphometric analysis. Results: A significant amount of new bone was detected in the gap given by the shape of the implants. Bone formation was exaggerated in the immobilized compared to the control group. No substantial difference in bone formation was observed between the group immobilized vs. soluble rhBMP-2.
Conclusion: It was shown for the first time that immobilized rhBMP-2 induces new bone formation in the woven petrous bone. Due to the immobilization this effect can be localized to the implant surface, thus preventing ectopic bone formation. Clinical goals for the application of rhBMP-2 in otology differ from those in other skeletal parts: Depending on the carrier material possible indications include obliteration/augmentation of large mastoid cavities, reconstruction of the posterior canal wall, improvement of osseointegration of various implants. If BMP-induced bone formation was possible in the ossicles, rhBMP-2-coated implants could serve as a guideline for bony restoring of necrosis of the long processs of the incus or even for creating a missing stapes-superstructure. Many further aspects have to be examined prior to such goals.

9.4

Comparison of hydroxyapatite PORP efficacy in ossicular chain reconstruction with autograft incus

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Purpose: Ossicular chain reconstruction is an important intervention in chronic otitis media, synthetic prostheses or autograft / homograft ossicles are used in these procedures. In this descriptive study we compared the extrusion of Hydroxyapatite PORP with that of autograft incus and Hearing level after surgery in 1993 - 2000 in Hospital affiliated Isfahan Medical School.

Material and Methods: From total of 39 patients reconstruction were made by autograft Incus on stapes capitulum and hydroxyapatite PORP, in 27 (69.2 %) patients by autograft incus (group 1) and in 12 (30.8%) patients by hydroxyapatite PORP (group 2).

Results: There was not prostheses extrusion in group 1 and there was 1(8.3%) patient prostheses extrusion in group 2. In the group 1 mean of preoperative air-bone gap was41 db and postoperative air-bone gap was 21.1 db.

In the group 2 mean of postoperative air-bone gap was42 db and postoperative air-bone gap was 20.8 db.

Conclusion: Autograft incus provides acceptable hearing and low risk extrusion in ossicular chain reconstruction.

9.5

Initial experience with titanium MVP clip prosthesis

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Introduction: After introduction of stapes surgery malleovestibulopexy (MVP) was the natural extention of this procedure. Although the hearing results of stapes surgery were ususlly excellent, the hearing results of MVP were quite variable. This probably resulted from poor understanding of middle ear mechanics and usage of the same prosthesis as used for stapes surgery. Modification of prosthesis design and technique has resulted in improved hearing outcomes after this procedure. Purpose: To evaluate the hearing outcomes of malleovestibulopexy using titanium MVP clip prosthesis which has recently been introduced.

Material and Methods: Six patients undergoing exploratory tympanotomy for congenital conductve hearing loss or failed stapes surgery and requiring malleovestibulopexy are included in this study. Extended tympanomeatal flap was employed for exposure of middle ear and upper malleus handle. The prosthesis was introduced and the clip was slipped on malleus handle. Minor adjustments were required to attain the perpendicularity of the shaft and shaft insertion in the vestibule. Drilling of handle with diamond burr was required in half the cases to better adapt the clip on malleus handle.

Results: The mean of air-bone gap averaged over speech frequencies was within 20 dB in all six cases and within 10 dB in four cases. No deterioration of bone conduction threshold was observed.

Conclusions: The hearing resuts of malleovestibulopexy using newly introduced titanium MVP clip prosthesis have been encouraging and almost equal results of stapes surgery. The improved results seem to be consequent to the unique design of the prosthesis which factors in two key variables of this procedure viz anchorage of prosthesis on malleus handle and perpendicularity of the prosthesis shaft in relation to stapes footplate.

9.6

Development of a new clip-piston prosthesis for the stapes

G. Schimanski[1], U. Steinhardt[2], A. Eiber[3], Luenen[1], Dusslingen[2], Stuttgart[3]; Germany

Inserting 275 Clip-Pistons type "a`Wengen" within three years have revealed difficulties in about 15 % of the cases. In that case it was necessary to deform the clip plastically before insertion due to the different dimension of the long process of incus. During more than 100 middle ear surgeries in the region where the clip is attached the cross section of the long process of incus was measured. This led to data which have not been known before. By virtue of a Finite Element model these data could be used for optimization of the form of clip. Design criteria were a minimal variation of the contact force for different cross sections and a minimal force to sliding on the clip over the incus process. The new clip design has a lower stiffness and therefore it is applicable for different diameters of incus process. The lower contact force reduces the risk of arrosion. Due to its optimized shape, the maximal stress in the clip is lowered which prevent a plastic deformation during insertion. The force to slip on the clip could be decreased by one third. This leads to an easy and safe application reducing the risk of damaging the ossicular chain like luxations of incus-stapes joint.

9.7

Partial ossicular reconstruction – experimental and clinical comparison of three different prostheses

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Closure of the tympanic membrane and reconstruction of the ossicular chain to restore patients hearing are the main issues of tympanoplasty. Depending on the intra-operative findings the extent of ossicular damage requires a partial or total ossicular reconstruction. Focusing on the case of a functionally intact stapes and interrupted long incus process we used three different methods for partial reconstruction aiming to determine a superior method for acoustic ossicular-prosthesis coupling: (a) Incus-interposition, (b) titanium clip-prosthesis and, in contrast to the stapes elevation techniques, (c) bridging a defect between the long incus process and the stapes by an angle-prosthesis. Measurements on 18 temporal bone specimen (n= 6 per group), prepared according to the mentioned defect and reconstructed respectively, were compared with the post-operative audiological outcome of 50 patients with matching middle ear pathology. LDV measurements were performed on the stapes footplate with an intact cochlear and normal air-conduction stimulation (96 dB). Pre- and post-operative audiograms were used to assess the development of the air-bone gap; middle ear aeration was determined by valsava´s maneuver and tympanometry. In the experimental setting no significant differences in sound transmission were observed between the groups. A tendency to an inferior transmission in lower frequencies was detected using an angle-prosthesis. Generally, when compared with equal clinical settings in patients who underwent middle ear surgery, the reconstructed middle ear in vivo lags behind the experimental setup in vitro. None of the used prostheses for ossicular chain reconstruction was superior to another in the experimental setting, if the prosthesis was inserted without any prestress or angulation, indicating nearly similar prosthetic-coupling properties of sound conduction. Experimental and clinical results do not generally favour the use of one specific prosthesis in the characterised setting, rather than suggesting the correct choice of a prosthesis upon the anatomically and patho-physiologically conditions found in the individual patient.

9.8

Functional evaluation of middle ear prostheses

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In order to improve new materials for middle ear prostheses, a method for evaluation of the transfer function of these materials had to be developed. The measurements were performed in three stages. Firstly, a mechanical middle ear model was designed which should simulate the mechanical and acoustical characteristics of an intact middle ear. In this model different conventional and new prostheses were measured by means of laser Doppler velocimetry (LDV). To control the stiffness of the system, we used tympanometry as well as multifrequency tympanometry (MFT). In the second and third stages the same evaluations were followed in fresh human temporal bones and animal experiments. The measurements in the mechanical middle ear model indicated a good comparability with the transfer function of an intact middle ear, particularly up to resonance frequency of the middle ear, which was about 1200-1500 Hz. The influences of mass and stiffness could be determined appropriately using the middle ear model. The measurements with different prostheses resulted in no significant variations in the transfer functions of commercial and new implants. The results of experiments on fresh temporal bones again showed no significant variation in the transfer functions of different prostheses. A median damping of about 15 to 20 dB particularly beyond the resonance frequency, was measured using implanted prostheses relative to the transfer function of an intact ossicular chain. Also the results of LDV and MFT measurements in animals on the implanted and non-implanted side (300 days postoperative) will be presented.

9.9

No more crimping in stapedotomy? A multicentre trial with the Nitinol stapes piston

GP. Rajan[1], AM. Huber[2], R. Blackham[3], RH. Eikelboom[3], MD. Atlas[1], Perth; Australia[1,3], Zurich; Switzerland[2]

Background: Manual piston malcrimping in stapedotomy is thought to be the major cause of the occurrence of the significant variations of postoperative air-bone gap closures (ABGC) and postoperative recurrences of conductive hearing loss. To bypass the drawbacks of manual crimping on stapedotomy outcomes, the self-crimping, shape memory alloy Nitinol stapes piston was utilised and its impact on hearing outcomes evaluated.

Study design: Prospective, multicentre study involving three tertiary care referral centres.

Methods: 60 patients with otosclerosis undergoing primary Laser-stapedotomy using the the Nitinol stapes piston were matched to reference patients from a conventional titanium piston database. The effects of the self-crimping Nitinol piston on the postoperative ABGC, the postoperative air-bone gap (ABG) variations and the postoperative hearing results were investigated 3, 6 , 12 and 18 months postoperatively. These data were statistically compared with the results of the matched control patients in the titanium stapes piston database and the data of our pilot study.

Results: The mean postoperative ABG and the interindividual variations of the postoperative ABG were significantly smaller in the Nitinol group. The postoperative reliability of ABGC after 18 months of followup was similar in both groups. No infections or adverse reactions occurred during follow up. Conclusion: Our mid term results after 18 months of followup confirm the data of our pilot study. They show that the self-crimping shape memory alloy Nitinol stapes piston bypasses the drawbacks of manual malcrimping in stapedotomy, thus optimising the surgical procedure. This allows consistent air-bone-gap closure in patients with otosclerosis.

10.1

A new implantable middle ear hearing device for mixed hearing loss: A feasibility study in human temporal bones

G. Ball[1], A. Huber[2], Innsbruck; Austria[1], Zurich; Switzerland[2]

It was the objective of a study to assess the feasibility of a new active, middleear device that is designed for patients with mixed hearing loss subsequent to chronic ear surgery or middle ear trauma. This prosthesis (PORP-Vibroplasty) is built of a VIBRAMT MED-EL Vibrant Soundbridge® and a Kurz Bell® titanium partial ossicular replacement prosthesis (PORP).

In three fresh temporal bones the normal and reconstructed middle ear was analyzed by laser Doppler interferometry. Sound transmission properties of a PROP, a passive and an active PORP-Vibroplasty were compared to the normal middle ear function.
The measurement method provided reliable results with small standard deviations and good signal to noise ratios (SNRs). PORP and the passive PORP-Vibroplasty performance were comparable to normal middle ear function. The activated PORP-Vibroplasty provided linear function and a flat frequency response within the measured frequency range (500Hz - 8kHz) with peak deviations of less than 10dB. The maximum output of the PORP-Vibroplasty was equivalent to 125dB SPL.

In conclusion the PORP-Vibroplasty implantation is feasible in temporal bones. PORP-Vibroplasty performance is sufficient to allow for a clinical trial as a next step.

10.2

On the optimal coupling of an implantable hearing aid – measurements and simulations

A. Eiber[1], C. Breuninger[1], J. Rodriguez Jorge[2], HP. Zenner[2], MM. Maassen[2], Stuttgart[1], Tübingen[2]; Germany

The Otologics Middle Ear Transducer (MET) is a partially implantable electro-magnetic middle ear hearing device to excite the ossicular chain mechanically. Its driving rod is pushed against the incus and the applied preload plays an important role in the sound transfer.

The objective of our investigations is to assess the optimal static preloading of the MET. They are subdivided into the two branches, experiments and simulations. For the measurements with Laser-Doppler vibrometry human cadaveric temporal bones have been used. Simulations have been carried out with computational models of the middle ear with its adjacent structures and also of the MET. They are based on modelling techniques such as Finite Elements and Multibody Systems approach known from dynamical analyses of mechatronical systems.

From the measured vibrations, the transfer functions between umbo, incus and particular points of footplate were calculated. After implantation of the MET, transfer functions between transducer and ossicular chain have been measured for different coupling preloads. An optimal transfer function between the MET-transducer and the oval window could be observed when the driving rod was firmly attached to the incus and moderately preloaded. An additional preload resulted in an attenuation of transfer. Additionally, the distortion of sound transfer increased by increasing preload.

Parallel to the measurements, simulations based on the mechanical models have been carried out and the experimental findings could verify the models. A particular attention was drawn to the modelling of the coupling between actuator and ossicular chain. These mechanical models allow detailed investigations of the transfer behavior depending on several parameters, e.g. position of attachment point or preload of coupling by carrying out sensitivity analyses. Predictions can be made concerning creeping effects of ligaments or different ways of insertion of the active transducer.

Applying multicritera optimization procedures allow for finding optimal values of design parameters with respect to sound transfer within certain frequency ranges or applicable preloads of coupling.

10.3

Optimizing the coupling load for the Otologics middle ear transducer MET: intra operative measurements

J. Rodriguez Jorge, M. Pfister, R. Ciuman, HP. Zenner, MM. Maassen, Tübingen; Germany

Introduction: The appearance of novel implantable hearing devices represents a hopeful alternative for the therapy of sensorineural hearing loss. One of these is the MET ossicular stimulator (Otologics, LCC., Bolder, CO, USA), a semi-implantable hearing aid with an internal unit consisting of an electromagnetic transducer. This internal unit is coupled to the incus by a coupling rod that is inserted in a previously made whole and adjusted by a microadjustive screw to achieve an optimal static preload resulting in maximum footplate displacement. Determining the optimal preload by acoustical measurements is limited intraoperatively due to possible occlusion effects of the ear canal.

Material and Methods: Acoustical and mechanical measurements were done simultaneously three MET implantations. A probe microphone that was inserted into the subsequently sealed ear canal was used for the acoustical measurements. For the vibration measurements, the developed and subsequently optimized setup according to Rodriguez Jorge et al. [1] was used consisting of a laser Doppler vibrometer (LDV) that is coupled to an operation microscope. We stimulated the MET ossicular stimulator with 9 simultaneous pure tones (250 Hz, 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 6000 Hz) and the microadjustive screw was turned to obtain the maximum incus displacement amplitude. The incus vibration amplitude was measured twice while the laser beam was focused onto the incus body.

Results: The highest amplitudes (40 µm/V - 80 µm/V) were found with a screw rotation of 0° - 90° (0 to 0.0625 mm). If the microadjustive screw was rotated 180°, the amplitude decreased by 14 dB - 20 dB. Altogether, an optimal coupling was achieved with a rotation of 90° corresponding to a coupling rod advancement of 0.0625 mm.

Conclusions: 1. The described setup is a sensitive and precise technique for intraoperative measurements in the submicroscopic range. 2. We recommend a MET advancement lower than 0.0625 mm to avoid overloading.

[1]Rodriguez Jorge J, Zenner HP, Hemmert W, Burkhardt C, Gummer AW. Laser vibrometry. A middle ear and cochlear analyzer for noninvasive studies of middle and inner ear function disorders HNO: 1997 Dec;45(12):997-1007.

10.4

Acoustical gain of a non-implantable electromagnetic hearing aid: Experiments using human temporal bones

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Purpose: To circumvent some of the problems inherent in conventional hearing aids, such as low gain at high frequencies due to acoustic feedback and discomfort in occlusion of the external ear canal, implantable hearing aids have been developed over the past two decades. However, since invasive surgery is necessary for implantation of these hearing aids, they have not as yet been widely employed. We have constructed a prototype of a non-implantable electromagnetic hearing aid which is mainly composed of a microphone amplifier system and an electromagnetic transducer. It can generate an excitation force to vibrate the ossicles by a coil adhered to the tympanic membrane. The electromagnetic transducer generated an excitation force equivalent to 93 dB SPL at frequencies between 0.5 and 10 kHz in an artificial middle ear and guinea pig ears. The suitability of this electromagnetic hearing aid for use in humans, however, is uncertain because frequency characteristics of human ears are different from those in artificial middle ears and guinea pig ears.

Materials and Methods: The acoustical gain of this electromagnetic hearing aid was evaluated in five human temporal bones extracted from cadavers. The frequency response of the displacement amplitude at the stapes was measured with a laser Doppler velocimeter when sound pressure was applied to the microphone of the hearing aid by an earphone. Next, the hearing aid was removed and the frequency response of the stapes was measured again with the same acoustic stimulation as that delivered to the hearing aid.

Results: With a constant sound pressure of 60 dB SPL, the mean acoustical gain was more than 20 dB even at high frequencies up to 6.0 kHz.

Conclusion: This newly developed hearing aid is applicable to patients with high-frequency hearing loss.

10.5

Implantable Microphone: A Middle Ear Ossicular Vibration Sensor

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With upcoming fully implantable cochlear implants and hearing aid systems, there is a big demand for implantable microphones that accomplish the characteristics of a typical hearing aid microphone. An implantable microphone based on a vibration sensor is presented. The idea of the approach is to incorporate the normal middle ear function into the implantable microphone and to make use of the middle ear and outer ear transfer characteristics. The tympanic membrane serves as a natural microphone membrane that transfers the sound signal into structural vibrations of the ossicular chain. These vibrations are picked up by a piezoelectric sensor at the long process of the incus. Numerical simulations are compared with experiments performed on human cadaveric temporal bone preparations comprising an experimental prototype of the piezoelectric sensor. Experiments, simulations and the process of mathematical model building affecting the sensor design are discussed.

10.6

The effect of cochlear implant electrode insertion on middle ear transfer function as measured by in-vivo laser doppler vibrometry

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Background: Preservation of residual low-frequency hearing with addition of electrical speech processing can substantially improve the speech perception abilities and hearing in noise of cochlear implant users. To utilise preserved low frequency hearing requires an intact middle ear conductive mechanism in addition to inner ear mechanisms. Little is known about the effect of a cochlear implant electrode on middle ear function. Aim: The aim of this study is to investigate the impact of cochlear implant electrode insertion on middle ear low frequency

transfer function. Patients and methods: Stapes displacement was measured in seven patients undergoing cochlear implantation. Measurements were carried out intra-operatively before and after electrode insertion. Each patient acted as their own control. Sound was delivered into the external auditory canal via a speaker and calibrated via a probe microphone. The speaker and probe microphone were integrated into an individually made ear mould. Ossicular displacement to a multisine stimulus at 80 dB SPL was measured at the head of stapes via the posterior tympanotomy using an operating microscope mounted laser Doppler vibrometry system. Results: Insertion of a cochlear implant electrode into the scala tympani has a variable effect on stapes displacement. In three patients, there was little change in stapes displacement following the electrode insertion. In two patients there was a significant increase, while in a further two there was a significant reduction in stapes displacement. This variability may reflect differing loss of perilymph associated with the electrode insertion and subsequent alteration of cochlear impedance. Conclusion: Insertion of a cochlear implant electrode produces a change in stapes displacement at low frequencies, which may have an effect on residual low-frequency hearing thresholds.

10.7

A new implantable hearing system for moderate-to-severe mixed hearing loss

H. Mojallal[1], C. Stieger[2], E. Grasshof[1], R. Haeusler[2], T. Lenarz[1], Hannover; Germany[1], Berne, Switzerland[2]

The adequate supply of the patients with moderate-to-severe mixed hearing loss (MHL) is not sufficiently possible with conventional hearing aids. These patients have enough cochlear reserve, but the additional middle ear disorder limits the usage of conventional hearing aids (gain limitation and distortion). The second possibility for such patients would be the bone conduction hearing aids, which indicate an insufficient gain for moderate-to-severe MHL. On the other hand because of good cochlear reserve there isn't an indication for cochlear implantation. Therefore there is no an optimal way to give an adequate gain to patients with moderate-to-severe MHL. The new improved DACS-system (Direct Acoustic Cochlea Stimulation) realizes a direct transfer to the inner ear. In this way the conductive disorders of middle ear dose not have any influence on the sound transfer. After an introduction of the functional principle of the system the pre and post operative audiological results of 4 implanted patients will be presented in this lecture. The one year post operative results indicate a functional gain of about 50 dB HL and an SRT improvement of about 40 dB SPL.

11.1

Keynote Lecture

A clinical perspective on non-middle ear causes of an air-bone gap

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Purpose: The majority of cases of an air-bone gap (as determined by audiometry) are the result of various middle ear pathologies that affect the tympanic membrane or the ossicular chain. However, there are a number of disorders affecting the inner ear that can present with an air-bone gap. The air-bone gap in such cases can be quite large, up to 40 to 50 dB. Furthermore, such a patient typically has otoscopic findings of a normal tympanic membrane and an aerated middle ear. Therefore, such a patient is often mistaken to have stapes fixation due to otosclerosis, resulting in unnecessary middle ear surgery on many occasions. In addition to their clinical importance, these disorders can be considered as experiments of nature, and investigation of their mechanics can provide unique insight into transmission of sound by air and bone within the middle and inner ear.

Material and Methods: This presentation will review our clinical experience with a number of inner ear disorders, all presenting with an air- bone gap (an apparent conductive hearing loss) without vestibular symptoms. These include dehiscence of the superior semicircular canal, enlarged vestibular aqueduct, Paget's disease, intralabyrinthine schwannoma, and occlusion of the round window (by a high jugular bulb, for example).

Results: The presentation will review clinical features of these conditions, possible mechanisms leading to the observed air-bone gap, methods that might permit an accurate diagnosis, and promising areas for future research.

[Supported by the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, USA]

11.2

The effects of superior semicircular canal dehiscence on hearing: Does size of the dehiscence have an impact?

GP. Rajan, A. Whyte, MD. Atlas, RH. Eikelboom, Perth; Australia

Background: Various effects of the Superior Semicircular Canal Dehiscence (SCCD) on hearing have been described. We investigated wether size of the SCCD has any impact on the frequencies in acoustic-evoked electronystagmography (ENG)responses.

Study: Retrospective study of 14 patients who underwent closure of SCCD out of a group of 22 patients with symptomatic SCCD. The stimulator frequencies pre-and postoperatively during acoustic- evoked ENG were compared and shifts in stimulator frequencies recorded. Size of SCCD preoperatively and postoperatively was calculated radiologically and correlated with any alterations of stimulator frequency in acoustic-evoked ENG.

Results: Out of the 10 patients analysed so far, 7 patients showed resolution of symptoms with effacement of the acoustic-evoked stimulator frequency. 3 patients showed recurrence of symptoms between 3 and 6 months postoperatively, out of these 2 showed shift of stimulator frequency to higher frequencies, radiologically incomplete sealing with smaller than initial SCCD was demonstrated, in the remaining 1 patient no shift of stimulator frequency occurred, radiologically complete breakdown of SCCD sealing was evident.

Conclusion: Our results suggest that size of the dehiscence influences the stimulator frequency in acoustic-evoked ENG for SCCD. Size of dehiscence seems to correlate inversely with the level of stimulator frequency, larger dehiscences displaying lower stimulator frequencies

11.3

Measurements of human inner-ear function with superior semicircular canal dehiscence (SCD)

ME. Ravicz[1], W. Chien[2], JE. Songer[3], JJ. Rosowski[2], SN. Merchant[2], Boston[1,2], Cambridge[3]; USA

Purpose: Superior semicircular canal dehiscence (SCD) syndrome is a recently-described clinical condition that offers an opportunity to investigate inner-ear sound conduction in human ears. Patients with SCD show a break in the superior or lateral wall of the bony superior semicircular canal, frequently have oscillopsia and sound- and/or pressure- induced vertigo, and may show a low-frequency conductive hearing loss of as large as 50 dB. It has been hypothesized that the dehiscence introduces a "third window" into the inner ear that shunts acoustical energy into the brain via the semicircular canal (causing the vestibular symptoms) and away from the cochlea at low frequencies (causing hearing loss). Such a shunt is expected to produce (1) sound-induced fluid velocity within the open dehiscence, (2) a reduction in sound-induced round-window velocity by shunting sound-induced fluid velocity away from the cochlea, and (3) an increase in sound-induced umbo and stapes velocities by increasing inner-ear input admittance.

Material and Methods: Middle- and inner-ear mechanics in SCD were explored in a human temporal-bone preparation: stapes, umbo, and round-window velocities were measured in response to air-conducted sound (a) with the inner ear intact, (b) with a dehiscence in the superior canal, and (c) with the dehiscence patched. Sound-induced fluid velocity in the open dehiscence was also measured.

Results: Dehiscences larger than 1 mm2 caused 10-22 dB reductions in round window velocity below 200 Hz (implying a 10- 22 dB hearing loss) and small but statistically significant increases in stapes velocity below 4 kHz and reduced umbo velocity between 0.3-1 kHz. These SCD induced changes were reversed on patching the SCD. Significant sound- induced fluid velocity was observed in the open dehiscence.

Conclusion: Results are consistent with hearing loss and umbo velocity measurements in SCD patients and with the predictions of the "third window" hypothesis. [Supported by NIDCD

11.4

Interest of measuring the resonance frequency of the ear using TEFLAG test in Menière patients exposed to changes in atmospheric pressure

M. Camicas[1], P. Avan[2], St. Martin[1], Clermont-Ferrand[2]; France

Purpose: Menière patients often report an improvement of symptoms when they are submitted to rapid change in height and atmospheric pressure. The Meniett device is somehow based on the principle that pressure changes are applied to the patients' stapes, yet no thorough validation of this concept has been brought forward so far. This test (Teflag II) consists in producing a negative pressure (-400 daPa) in the sealed external auditory canal (corresponding to a change in height of about 1200 ft), maintained for 20 min with the help of a multi-frequency impedancemetric device Grason-Stadler GSI 33 V2.

Methods: A preliminary study has been performed on 43 ears, 30 normally-hearing ones, 9 with Menière's disease and 15 with a variety of non-Menière, sensorineural deficits. The resonance frequency of the ear (RF) and the shape of susceptance (B) at 2 kHz have been measured before and just after the -400 daPa depression was applied.

Results: In normal ears, the mean RF was 940 Hz before, 887 Hz after the depression (-53 Hz), and B morphology was unchanged in more than 80% cases. In Menière ears, RF decreased from 1154 Hz before, to 928 Hz after depression (-226 Hz). In other types of deafness (e.g., of occupational origin, n = 19), RF decreased from 852 to 692 Hz (-160 Hz). Conclusion RF tended to be larger in Menière ears. More characteristically, the change observed in Menière ears was 4 times larger than the one in normal ears. Although it lasted only a few hours, it lined up with a clinical improvement in relation to pressure applied to the stapes through the tympanic membrane and ossicular chain. A rather similar, although quite smaller effect was observed in other types of sensorineural deafness. These results will be discussed in relation to a possible diagnostic interest.

11.5

First application of fully implantable hearing aids in patients with congenital auricular atresia

S. Mattheis, R. Siegert, Recklinghausen; Germany

Congenital auricular atresia is a malformation with an incidence of 1:8000. Whereas the inner ear anatomy and function is normal in most of these patients, they suffer from a conductive hearing loss with an air-bone gap of 60 dB. Conventional bone conducting hearing aids or bone anchored hearing aids (BAHATM) are current treatment options with several disadvantages. Transcutaneous implants require constant attention to hygiene to avoid infections. The mode of operation is to vibrate the entire skull, thereby destroying binaural cues that a patient might want to use for directional hearing and speech recognition in noise.

Surgical construction of the sound conducting apparatus has been performed by others and modified by us into a three-step procedure with in-vivo prefabrication of the external ear canal and the tympanic membrane (Laryngoscope 113, 2021 - 2029, 2003). Although the results improved after inauguration of our modifications, there still remains an air-bone gap that makes air conducting hearing aids necessary in many patients.

Implantable hearing aids have been developed for patients with perceptional hearing loss and normal middle ear function, but not for patients with middle ear disease or malformation.

We have modified the surgical instruments, the transducer and the operative technique of the only fully implantable hearing aid (Otologics Fully-Implantable METTM) clinically available and implanted it in five patients with congenital auricular atresia.

After activation and fitting of the devices we see an improvement of the sound-field thresholds up to 50 dB HL. The mean functional gain in a three frequency pure tone average is about 35 dB HL.

This technique seems to provide a completely new dimension for the audiological rehabilitation of patients with severe malformation of the middle ear.

11.6
Invited Paper

Middle ear morphometry from cadaveric temporal bone micro-CT imaging

S. Puria, J. Sim, J. Tuck-Lee, C. Steele, Stanford; USA

Purpose: Our goal is to develop anatomically based biomechanical models of middle ears for which middle ear morphometry data is critical. To obtain morphometry of the middle ear, histological methods have been the primary technique. However, this technique is destructive and certainly not appropriate for in-vivo imaging of individual subjects. One of the most recent advances for obtaining anatomical information is computed-tomography with um resolutions (microCT). This has been used to obtain volume reconstructions of the temporal bone of living subjects at a resolution of less than 125 µm. In-vitro resolution can be increased by an order of magnitude. Here we describe methods to determine parameters, needed for computational models, from the microCT imaging modality. Material and Methods MicroCT images, at 10-20 um resolution (both in plane and out of plane), were obtained from cadaveric temporal bone ears of human, cat, chinchilla and guinea pig using a Scanco VivaCT 40 scanner. The high-resolution images (1000 to 2000 slices) were used for 3D reconstructions of the ossicles, suspensory ligaments and tendon, tympanic membrane eardrum curvature and its relative position in the ear canal, tympanic membrane thickness, and middle ear cavities.

Results: Results indicate significant inter-subject variability amongst individual subjects and across species. Morphometry measurements will include calculations of: (1) principal axes and principal moments of inertia of the malleus-incus complex and stapes, (2) dimensions and angles of suspensory ligament and tendon attachments relative to the principal axis, (3) malleus-incus joint spacing, (4) Eardrum thickness as a function of position, (5) middle ear cavity volumes and location of septa and foreman (when present).

Conclusions: Most of the middle ear structures, including the tympanic membrane cone shape and thickness, ossicles, and suspensory soft tissue, can be visualized because there is often good density contrast between these structures and air in the ear canal and middle ear cavity. Because they provide the best resolution, histological methods remain the standard. However, microCT imaging offers some distinct advantages (Decraemer et al. 2003, JARO). These include: (1) elimination of stretching distortions commonly found in histological preparations, (2) use of a non-destructive method, (3) shorter preparation time (hours rather than 12-16 months), and (4) results already in digital format.

11.7
3-Dimensional virtual models of the human middle ear and temporal bone

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Purpose: The three-dimensional (3-D) anatomy of the human temporal bone is complex, and learning it poses a challenge for students in basic science and in clinical medicine.

Material and Methods: We have developed 3-D models of various parts of the temporal bone and surrounding structures using histological sections from normal ears. Sections were digitized and then imported into a general purpose 3-D rendering and analysis software package (Amira v3.1, Mercury Computer Systems/TGS, San Diego, CA). The sections were aligned, anatomical structures of interest were segmented, and various models were generated.

Results: The resultant models are surface renderings of structures of interest. For each structure, the surface transparency can be individually controlled, thereby revealing the 3-D relations between surface landmarks and underlying structures. The 3-D surface models can also be sliced open at any section and the appropriate raw histological image can be superimposed on the model. The stack of images can also be re-sectioned in other planes. We have also developed a freeware 3-D viewer which allows our models to be downloaded from our website onto PC, Mac, and Linux platforms. The 3-D viewer allows full rotation and transparency control as well as the ability to slice open the model in x, y or z planes. The presentation will demonstrate real time versions of our models and various features of the 3-D viewer.

The models can be downloaded as freeware at https://research.meei.harvard.edu/otopathology/3dmodels

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11.8
Demonstration of aeration pathways in the human epitympanum

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Aims: Aeration of the human epitympanum is a contentious area of study with conflicting opinions being held. It is hoped that a better understanding of the aeration pathways of the epitympanum, will bring some explanation of retraction pocket formation, the direction of spread of attic cholesteatoma and the development of recurrent disease after surgical treatment.

Methods: Histological preparations of serially sectioned human temporal bones were reconstructed in 3-D using the Amira (R) software package to show detail of Prussak's space, the associated mucosal folds and aeration pathways. This was correlated with clinical photographs from cadaveric dissections and injection studies of gel introduced by needle puncture into Prussak's space to simulate an expanding cholesteatoma.

Results: A number of common patterns of aeration pathway were demonstrated. It is proposed that certain patterns may be more likely to give rise to retraction and may also be responsible for the direction of spread of cholesteatoma once it has formed. Conclusion: These novel techniques are valuable in demonstrating attic fold anatomy and have allowed aeration pathways to be assessed in detail. It is hoped that this information will prove clinically relevant to the otologic surgeon considering tympanoplasty.

Poster

P1

Tympanic membrane structure analysis and tissue engineering

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Aim: To undertake electron microscopy and immunohistochemical studies of the normal human tympanic membrane as a basis to develop a tissue-engineered tympanic membrane. Background: The functional results of myringoplasty, using currently available graft materials, remains uncertain. A tissue-engineered tympanic membrane should theoretically improve outcomes. Successful tissue engineering of the human tympanic membrane requires an intimate understanding of the cytokeratin (CK) expression of the outer and inner layers, for identification of cells in cell culture, as well as the collagen components of the middle layer.

Method: Tympanic membrane structure was examined histologically using standard techniques of light and electron microscopy. CK expression of the outer and inner layers, was analysed by immunohistochemistry.

Results: Histology confirmed the three-layer structure of the tympanic membrane. The middle collagenous layer consists of outer radial and inner circular fibres, with parabolic fibres observed between them. CK 5, 10, 14, 16 and 19 are expressed in the outer layer. The outer epithelial layer consists of an outer keratinising stratum corneum with underlying stratum granulosum, stratum spinosum, and stratum basale layers. The thin inner mucosal layer consists of simple squamous or cuboidal cellsPositive staining of CKs 4, 7, 8, 18 and 19 occurred in the inner layer, with focal areas of CK 13 and 14. Collagen expression of the middle lamina propria is mainly types II and III, with type I to a lesser extent.

Discussion: CK expression of keratinocytes from the outer layer, and mucosal cells from the inner layer, enables us to test cell growth on different scaffolds and in different environments. We are progressing on our work to determine the collagen composition of the middle layer. There is good evidence to suggest that the middle layer provides the tension of the tympanic membrane and its loss results in a flaccid tympanic membrane, with impaired function. This knowledge is necessary for the development of an ppropriate scaffold to support cell growth.

P2

Bone conduction and air conduction hearing comparison

M. Bance, Halifax; Canada

Purpose: Many subjects who wear a BAHA or use bone conduction describe the sound as being tinny. This could be due to filtering of the skull or the BAHA transducer. The fine frequency response of BAHA bone conduction and air conduction have not been compared in the same subjects Methods: A fine frequency audigram in 100 Hz steps was performed in 5 subjects, from 200 to 8kHz using headphones. This was then repeated using a BAHA headband. The fine frequency response of these subjects for the two modalities was compared after normalizing for force output of the transducer and the earphones. Test-retest experiments were performed on two subjects to ensure stability of responses. Results: The bone conduction transducer (BAHA) had a poor low frequecy response compared to the headphones. Once corrected for, the fine frequency responses of air and bone conduction were very similar, with no sighns of narrow resonance peaks in either Conclusions: The tinny sound quality experienced by BAHA users is probably due to the poor low freqeuncy response of bone conduction with this device. Otherwise, air conduction and bone conduction have similar fine frequency hearing responses.

P3

Investigation on bone conduction thresholds in otosclerosis

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Concept: The comparison of pure tone bone conduction thresholds before and after stapes surgery in most cases reveals a significant improvement of the preoperative bone conduction loss in addition to the expected closure of the air-bone-gap. This bone conduction effect not only occurs in the range around 2000 cycles per second, known as the Carhart notch, but in the entire range with maximum postoperative threshold rise in low and middle frequencies (500-3000Hz).

The present study was devised to determine if the opening of the oval window during surgery alone already improves bone conduction.

Methods: Stapedectomy under local anaesthesia was performed in 24 patients with stapes fixation due to otosclerosis. We compared the bone conduction from preoperative audiograms with intraoperative thresholds measured directly after removing the footplate using a bone conduction tansducer at test frequencies 0.5, 1, 2 and 4 kHz. The patients have given written consent for this intraoperative measurement.

Results: Our data showed a clear improvement at 0.5, 1 and 2 kHz, but not at 4 kHz. Corresponding to the Carhart notch threshold rise is best at 2000Hz. Pure-tone-averages (PTA) were calculated from the collected data and statistically analysed. The improvement was significant for PTA from 0.5-2 kHz. No significance was found for PTA from 0.5-4 kHz. To investigate the underlying cochlear mechanisms a finite element model of the cochlea was used. It suggests an increased amplitude of the basilar membrane movement with an open oval window due to a lower impendance compared to the situation with a fixed footplate.

Discussion: These results give evidence for the fact that optimal basilar membrane movement is depending on the integrity of the cochlear windows. In a cochlea with totally fixed stapes there is "captured energy" which cannot properly act on the basilar membrane during bone conduction stimulation.

Conclusion: Therefore in otosclerosis the depression of bone conduction especially between 0,5 and 2 kHz is not a sensorineural but a mechanical deafness and can be surgical corrected. This is the first investigation where audiometry has been performed with opened oval window during stapedectomy. It directly explains the mechanical cause of parts of the depression of bone conduction in otosclerosis as already suspected by Carhart.

P4

Transcranial attenuation of bone conducted sound measured acoustically and psycho acoustically

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Background/purpose: The transcranial attenuation of bone conducted (BC) sound has been described in several investigations and has been determined from the vibrations of the skull bone or from the BC hearing thresholds. However, these studies report different results.

Methods: Four different methods were used on 20 normal hearing subjects to estimate the transcranial attenuation of BC sound. The ear canal sound pressure (ECSP) and the monaural BC hearing thresholds were obtained with stimulation from a BC transducer at the contralateral and ipsilateral mastoids and at the forehead. All measurements were made both with open and closed ear canal. The transcranial attenuation was determined by relating the result from the ipsilateral stimulation with the result from the contralateral stimulation. The attenuation between the forehead stimulation and the ipsilateral stimulation was determined in the same way.

Results: The transcranial attenuation increases with frequency with all methods. At low frequencies, the methods produced slightly different results. A closed ear canal gives slightly less attenuation than an open ear canal; at frequencies below 500 Hz, stimulation at the contralateral side gives a higher ECSP and a better BC hearing threshold than at the ipsilateral side. For frequencies above 800 Hz, similar results are obtained with all methods and the transcranial attenuation increases from 0 dB at 1 kHz to 15 dB at 8 kHz. The attenuation between stimulation at the forehead and the ipsilateral mastoid is, for all four methods, between 3 and 10 dB at frequencies between 0.7 and 4 kHz. For both higher and lower frequencies, the closed ear canal produces less attenuation.

Conclusions: The result of the transcranial attenuation in this study agrees fairly well with results from studies where the transcranial attenuation was derived from vibrations of the skull bone. The differences are greater for the attenuation between stimulation at the forehead and the ipsilateral mastoid. The relative BC sensitivity can be estimated by the ECSP at frequencies above 800 Hz.

P6

The effects of slight and rapid pressure oscillations on the pars flaccida in gerbil and rabbit ears

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It is generally accepted that the pars flaccida (PF) takes part in the regulation of very small pressure variations in the middle ear (ME). However, it is unclear how important the participation of the PF is for the physiology of the ME as well as for the physiology on the whole.

The aim of the study was to clarify whether the PF is capable of reacting to slight air pressure oscillations (PO) with amplitudes and frequencies typical for natural atmospheric pressure fluctuations in the far infrasound frequency range (APF), which constitutes the common noise in the atmosphere. If so, the PF can play an important role in the overall physiologic regulation processes, which make humans susceptible to far infrasound APF.

The linear displacements of points near the center of the PF in response to periodic PO with different amplitudes (from 4 to 105 Pa) and frequencies 200, 100, 50 and 10 mHz) were measured in vitro in four ears of gerbils and four ears of rabbits by means of laser Doppler vibrometry. The index of the PF reactivity to PO (Ra) was determined as the ratio of the amplitude of the PF oscillations (PFO) to the amplitude of the PO. All kinds of PO applied caused PFO in all the ears of gerbils and rabbits. The amplitude of the PFO increased when the amplitude of the PO was increased. In gerbils, a decrease in Ra with the increase in amplitude of the PO was observed and associated with a non-linear S-shaped curve of the PF displacement as a function of the pressure change. The S-shape was most pronounced at higher PO amplitudes, and the curve was straightening with a decrease in PO amplitude. In the range of the lowest amplitudes of the PO (4-20 Pa), where the curve had no S-shape, Ra proved to be 1.4 times higher than in the range of highest amplitudes of PO (90-105 Pa). Considering that the natural level of APF usually is within the range of 20 Pa, this fact points to an important contribution of the PF to the air pressure dynamics in the ME of gerbils. In rabbit ears the curves did not have the S-shape and the clear tendency of Ra to decrease with an increase in PO amplitude also was not revealed.

We observed a clear hysteresis in the PF displacement with respect to different directions of the pressure change at all kinds of PO applied to the ME in all the ears. The index Ra was lower (about four times) and the hysteresis slope was wider in rabbits than those in gerbils, which points to less reactivity and mobility of the PF in rabbits. Our findings are in line with the suggestion that the PF might play an important role in the regulation of transtympanic pressure variations in respect of ME adaptation to natural levels of slight APF.

P7

Biomechanical modeling and design optimization of cartilage myringoplasty using finite element analysis

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Purpose: The purpose of this study was to determine the acoustic transfer characteristics of cartilage for optimal cartilage tympanoplasty.

Material and methods: Cartilage specimens of the tragus were obtained from fresh human cadavers and were investigated by means of an ear canal-tympanic membrane model. The parameters of tragus were determined by curve fitting and cross calibration to Zahnert's study. The cartilage plate was reconstructed for ear drum perforation to our 3-dimensional middle ear biomechanical model. The optimal thickness of cartilage tympanoplasty was calculated by using finite element analysis.

Result: Reducing cartilage thickness lead to an improvement of its acoustic transfer qualities. From an acoustic point of view, the 0.3-mm cartilage plate seems to be preferable compared with tympanic membrane vibration.

Conclusion: Tragal cartilage is useful for reconstruction of tympanic membrane from the perspective of acoustic properties. The acoustic transfer loss of cartilage can be reduced by decreasing its thickness. A thickness of 0.3 mm is regarded as a good compromise between sufficient mechanical stability and low acoustic transfer loss.

P8

Computer modelling of static pressure changes in the middle ear

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The human ear is designed to respond to static or quasi-static pressure changes, which can result in displacements exceeding 0.5 mm, many thousands of times greater than the vibrational displacements at audiofrequencies. It has been suggested previously that the ossicular chain effectively 'decouples' at the incudostapedial joint under static pressure loading, in order to excessive prevent transmission to the inner ear. Previous work conducted in our group on fresh human temporal bones demonstrated that there is a gliding motion at the incudomalleolar joint.

The aim of this study was to investigate, using finite element modelling, the motion of the normal ossicular chain under static and quasi-static pressures, particularly to obtain a better understanding of how motion is affected by the stiffnesses of the incudomalleal and incudostapedial joints. As a starting point the incudomalleolar joint was assumed to be relatively stiff, in accordance with observations by Vlaming in 1987. The joint was modelled as a homogeneous and isotropic hard tissue with a Young's modulus identical to the ossicles (12,000MPa). The less rigid incudostapedial joint was modelled as homogeneous and isotropic ligamentous tissue with Young's modulus of 0.6 MPa. These stiffness values have been used by our group and by others in previous finite element models.
Deformation of the umbo under static pressure was found to be similar to our previous experimental findings. The variation of joint stiffnesses had very little effect on umbo deformation, but was found to have an important influence on the deformation of the stapes centre footplate. The effect of incudostapedial joint stiffness was greater than that of the incudomalleal joint. While the stiffer joints aided sound transmission, the high modulus of the incudomalleal joint used in finite element models precludes movements of more than a few tens of micrometres under static pressure, suggesting that a lower modulus would be more realistic. Decreasing the joint stiffness does, however, impact adversely upon sound transmission efficiency.

P9

High resolution 3-D imaging and modelling of middle ear ossicles and soft tissue structures of intact Gerbil temporal bones, using orthogonal-plane fluorescence virtual sectioning

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Detailed models of middle ear morphology are an important input to improve realism of computer models of middle ear mechanics. Histological sections are used to produce high quality models, but the method is extremely work intensive. CT data deliver models of the bony structures with reasonably good resolution, but soft tissue is much more difficult to image. Orthogonal-plane fluorescence optical sectioning or OPFOS, is an important additional technique which, after adequate specimen preparation, produces high quality, perfectly aligned sectional images in nearly real time, of both bone and soft tissue. The OPFOS technique was introduced by A.H. Voie (J. Microsc. 170, 1993), and was used to construct models of cochlea, with a slicing resolution of about 14µm. We have improved the OPFOS technique, so that slice thicknesses of less than 3µm can be achieved to measure shape of ossicles, muscles, tendon and even blood vessels in the middle ear. In conventional OPFOS, a plane of laser light is projected through a fluorescent specimen, and the light emitted from that plane in the object is observed in orthogonal direction, thus showing in real time a virtual section. To apply the technique, specimens need to be completely transparent, refractive index matched to a surrounding fluid, and made fluorescent. This is achieved by decalcifying, dehydrating, clearing with Spalteholtz fluid, and finally staining the specimen. The thickness of the laser plane is always a trade-off with the image size. Using improved optical design and adding motorized scanning along a direction of the image plane, we were able to overcome this limitation and reduce slicing thickness to 2µm, with an in-plane resolution of 1.5µm. To establish objective measurements of resolution, we compared our OPFOS results to data obtained from SEM, on a custom made plastic test object. We will show data of middle ear ossicles and soft tissue structures, such as the stapedial muscle and tendon. Measurements were obtained in preparations of intact temporal bones of Gerbils, as the technique allows region-of-interest scanning within a larger specimen. From the section data, we reconstructed 3-D models of the middle ear. In these models we are also able to show for instance the stapedial artery, which is nearly invisible on CT. Sections from our high resolution data show the hollow structure of the stapes head, cavities within the body of the ossicles, and other functional details. Fusion with CT data, obtained on the same specimens, can be used to discriminate between bony structures and soft tissues.

P10

Hyperelastic warping applied to x-ray micro CT images for the study of human middle ear chain deformations under static pressure load

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In everyday life the human ear is subject not only to sound but also to slow, quasi-static pressure variations with amplitudes orders of magnitude larger. The middle ear provides a mechanism to protect the inner ear from these excessive static pressures while at the same time it is able to process the sound signals. In the present study we investigated how the ossicular chain deforms and changes its 3-D configuration when acted upon by large static pressures. Fresh human temporal bones were within 60 hours post mortem used for the present experiments. Pressure ranging from -200 daPa to + 200 daPa was applied in steps to the external ear canal using a pressure generator. At each pressure step a scan of the entire temporal bone was recorded using an in-vivo x-ray micro CT scanner (Skyscan 1072). To determine with good precision the small deformations of the ossicular chain we use 'hyperelastic warping' (HEW, Rabbitt et al., 1995 SPIE 2573:252), a deformable image registration method. In this

relatively new technique a 3-D finite element model, based on careful segmentation of a template dataset at zero pressure, is being deformed (warped) until it aligns with a target dataset at a different pressure. Results of HEW were compared to more crude results obtained by aligning 3-D models, made by individual segmentation at each pressure step, using an Iterated Closest Point (ICP) algorithm. ICP calculates the translation and rotation between two models at successive pressure steps. With this technique the ossicles are presumed to behave as rigid bodies, a restriction that is not required in the warping technique. ICP and HEW show similar results. The absence of significant strains in the ossicles proofs further that the rigid body assumption is quite valid. 3-D displacement of the ossicles will be shown in an animation and expressed mathematically by plotting the displacement of a few landmark points as a function of pressure. The immediate screw axis for the motion of each individual ossicle was also calculated for each pressure step. The position of this axis along with the rotation about this axis and the slide along this axis are also shown as a function of pressure. This leads to a description of the changes in configuration and slippage in the ossicles explaining the protecting mechanism of the middle ear.

P11

Three-dimensional reconstruction and modeling of middle ear biomechanics using high resolution computed tomography and finite element analysis

TC. Liu, CF. Lee, WJ. Lee, JH. Chen, Taipei; Taiwan

Purpose: To present a systematic and practical approach that uses high-resolution computed tomography (HRCT) to derive models of the middle ear for finite element analysis (FEA).

Materials and methods: This prospective study included 31 subjects with normal hearing and no previous otological disorders. Temporal bone images obtained from 15 right ears and 16 left ears were used for evaluation and reconstruction. High-resolution computed tomography of temporal bone was performed using simultaneous acquisition of 16 sections with a collimated slice thickness of 0.625 mm. All images were transferred to an Amira visualization system for 3D reconstruction. The created 3-D model was translated into two commercial modeling packages, Patran and ANSYS, for finite element analysis.

Results: The characteristic dimensions of the model were measured and compared with previous published histological section data. The result confirms that the geometric model created by the proposed method is accurate except the tympanic membrane is thicker than that of histological section method. No obvious difference in the geometrical dimension between right and left ossicles was found ($p > 0.05$). The 3D model created by finite element method and predicted umbo and stapes displacements are close to the bounds of the experimental curves of Nishihara's, Huber's, Gan's and Sun's data across the frequency range of 100-8000 Hz.

Conclusion: The model includes a description of the geometry of the middle ear components, and dynamic equations of vibration. The proposed method is quick, practical, low cost and most importantly, non-invasive as compared with histological section methods.

P12

Imaging findings in Otosclerosis, a review study

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Purpose: To examine the CT findings and classifications in patients with otosclerosis.

Material and methods: We reviewed all consecutive patients with the presumption diagnosis of otosclerosis between 01.01.1995 and 28.02.2006 in the data base of the department of otorhinolaryngology.

Results: 291 patients were listed in the data base. In our institut 36 of 291 patients underwent CT examinations. In 11 of 291 patients we found the characteristic findings of otosclerosis. One male patient had findings of osteogenesis imperfecta. The ratio male to female was 10/1. In 9 of 10 the otosclerosis was bilateral, in 1 of 10 unilateral. In 6 of 10 patients the otosclerosis was retrofenestral, in 4 of 10 patients the otosclerosis was fenestral. 2 out of 10 patients had an unilateral implant.

Conclusion: Otosclerosis is a rare disease. In our study the typical findings of otosclerosis with otospongiotic and otosclerotic changes could nicely be demonstrated. Bilateral otosclerosis is present in about 85% of patients, which is similar to our study. There is normally a female predominace of 2/1, which could not be confirmed in our small group. In our study the retrofenestral type was found in 6 out of 10 patients and the fenestral type was present in 4 out of 10 subjects, contrary to the literature where the fenestral type makes up to 80%.

P13

Morphology of the tympanic membrane insertion into the temporal bone in humans

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The fibrous annulus of the eardrum is a rim of the pars tensa that binds the tympanic membrane to the inner surface of the tympanic bone. Despite of his importance on the vibratory properties of the tympanic membrane, the nature of his insertion is only partially described. Recently studies described the presence of contractile cells (myofibroblasts and smooth muscle cells) in the region of the fibrous annulus in animals and humans. The aim of this study is to better understand the morphology of the tympanic insertion and to confirm the presence of contractile elements. 7 specimens of human tympanic membrane (3 adult and 4 foetal) were studied. Techniques applied were electron microscopy and light microscopy using conventional and immuno staining techniques. We demonstrate the presence of contractile cells at the level of the interface tympanic membrane- fibrous annulus. In the adult these cells are rare and scattered and in the foetus they are numerous and richly interconnected. The finding of a real contractile rim in the foetus and its involution in the adults questions us on the role of these cells and their influence on the audition.

P14

Real-time opto-electronic holographic measurements of sound-induced tympanic-membrane displacements

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Purpose: The tympanic membrane (TM) is the initial structure involved in the middle-ear's acoustical-mechanical transformation of environmental sounds to sound pressure within the inner ear. While we know some basic facts about the workings of the healthy TM in a limited frequency range, many unknowns remain including how sound is coupled to the ossicles by the TM, especially at high frequencies, as well as the effects of pathology on TM function.

Materials & Methods: We use computer-assisted opto-electronic holography that employs fast, high-resolution digital cameras, highly sensitive piezo-controlled positioning stages and advanced signal processing techniques to generate holographic images of the motion of the entire TM at rates up to 500 frames per second. We use two techniques. (1) Time- averaging of the holographic images over several stimulus cycles generates iso-displacement contours of the magnitude of motion of the entire surface of the TM or (2) Stroboscopic holography determines the magnitude (with resolutions of 5-10 nanometers) and phase of the displacement of the surface of the TM. Preliminary measurements have been made in cadaveric cat and chinchilla ears with the middle-ears open.

Results: The TM displacement patterns observed are similar to those produced by others [Khanna & Tonndorf JASA 51:1904-20, 1972] at frequencies less than 4 kHz, however, the holograms determined with stimulus frequencies above 4 kHz show clear standing waves with inter-maximal distances consistent with surface wave velocities of about 10 m/s. The displacement patterns on the chinchilla TM indicate larger displacements and a downward shift in the frequencies needed to observe complex patterns of TM motion consistent with the mechanical hypersensitivity of the chinchilla middle ear. Conclusions Opto-electronic holography rapidly determines the motion of the entire TM surface. The preliminary data suggests surface waves of TM motion and clear interspecies differences in TM function. [Supported by NIDCD and WPI]

P15

Tele-otology - a tool for education and telemedicine

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Background: The increasing accessibility and convergence of computer and imaging technologies has placed new tools in the hands of ear and hearing related clinicians. Video-otoscopes now produce high quality images, are compact and safe to use, and can link directly to a personal computers. Australia is faced with the challenge of providing ear specialist services to scattered populations across large areas, where there is a high incidence of ear disease.

Aim: To develop a tele-otology tool to improve the level of ear health care for people in remote areas.

Methodology: We have developed a tele-otology system with software that captures, stores and transmits (i) still images from a video-otoscope, (ii) a clinical history and (iii) audiometry data. If required, this information can be transmitted via a network connection to a server and then to an ear specialist for assessment and advice. We describe three scenarios in which we have incorporated this into clinical practice.

I. Meekatharra (population approx 800) is 1000km from the nearest city with very high incidence of chronic otitis media. Equipment and training for health care workers were provided to enable images, clinical history and test data to be sent to an ear specialist. Between Nov 2003 and Oct 2005 181 telemedicine consultations were provided.

II: Darwin: An audiologist in a city hospital setting utilised the tele-otology system for pre- and post-surgical assessment of patients, manage surgery lists, and education of patients and parents. 150 patients were assessed between Mar and Oct 2005, some of whom were seen on remote islands.

III. Kimberleys, Western Australia: 206 children in 12 remote communities were seen at schools in a three week period by an audiologist. The tele-otology system was used for education of patients, parents and teachers. Data on 20 patients with dry perforations was provided to an ear specialist. Outcomes: (i) Validation of tele-otology as method of improving assess for people in remote areas to an ear specialist. (ii) Validation of the video-otoscope as an educational tool. (iii) Validation of the tele-otology system as a tool in the surgical management of patients, particularly those travelling to and from remote areas.

P16

Anatomy of the distal incus and lenticular process in the human

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Purpose: The distal incus is the site of coupling to the stapes, and is also the site of bone erosion in middle-ear disease. Yet, little attention has been given to its anatomy.

Material and Methods: Histological sections from 103 normal temporal bones ranging from infants to age 100 years were examined. Measurements were made of various morphometric parameters of the distal incus and lenticular process. Three-dimensional reconstructions of this region were created for selected specimens.

Results: The anatomy of the incus differs from descriptions in standard texts. The lenticular process has two distinct components- a proximal narrow "stem" (mean diameter 216 microns) and a distal expanded "cap" (mean diameter 710 microns). The capsule of the incudo-stapedial joint is unusual in that it attaches to a narrow area along the rim of the stapes head, expands considerably at the level of the stem, and attaches to the stem and cap over a broad surface area. Dimensions of the distal incus and lenticular process do not change with age. However, a significant decrease in number of osteocytes occurs with advancing age. The vascular supply to the distal incus and lenticular process comes from several nutrient vessels within the bone as well as from the mucosa.

Conclusions: The special anatomy of the distal incus and lenticular process may have functional significance in sound transmission. We (and others: Funnell et al. JARO 2005; 6:9-18) hypothesize that the stem bends, serving to isolate the stapes

from movements of the incus in certain directions while favoring motions along the long axis of the stapes. The ample vascular supply from nutrient vessels within the bone makes it unlikely that incus "necrosis" (e.g. after stapedectomy) is caused by a lack of blood supply. The slender stem of the lenticular process in combination with loss of osteocytes may serve to increase the vulnerability of the stem to bone resorption in chronic otitis media. [Supported by the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, USA]

P17

Do mesenchymal stem cells enhance the healing of chronic tympanic membrane perforations?

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Purpose: Assessment of a possible healing enhancement of human mesenchymal stem cells in chronic tympanic membrane perforations. Chronic tympanic membrane perforation commonly arises as a result of either trauma or otitis media resulting in conductive hearing loss and recurrent or chronic infection. It is a clinical problem in otolaryngology and the only treatment of choice is surgery restituting the perforation by suitable graft materials. In recent years stem cells have gained interest for its tremendous capability to mature into different specific cell types. We intend to test a simple treatment that could replace surgery so that the patients could be treated with a simple office technique. Material and methods: A laser myringotomy of 0.2mm diameter was made bilaterally in postero-superior quadrant of pars tensa of 12 Sprague Dawley rats. A cortisone solution was instilled bilaterally for 10 consecutive days to make a chronic perforation model. At 4 weeks after cortisone instillation a 0.5ml solution of human mesenchymal stem cells (1.2× 106/ml) was applied in right ears after refreshing the perforation edges. A saline solution was applied in the same way on the left ears for controls. Otomicroscopy was performed weekly after the stem cell treatment and the condition of perforations was documented. Six rats were treated with injection prograf (Tacrolimus)to prevent host versus graft rejection.The TMs were embedded according to standard method for light and electron microscopic examination. Results: 4/10 stem cell treated ears had closed perforations as compared with 2/10 saline treated control ears. Light and electron microscopic assessments are underway. Conclusion: The number of mesenchymal stem cells treated ears were closed twice as many as compared with control ears after one month. The number of studied animals is small, so the difference is not statistically significant and no major conclusions can be drawn. The tendency is, however, in favour of stem cell treatment.

P18

Identification of human papilloma virus DNA in chronic otitis media and middle ear neoplasms

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Purpose: The assesment of presence of HPV types 6, 11, 16, 18 DNA in middle ear pathologies.

Material and Methods: the examination was carried on a group of 53 patients, among which there was 39 cases of chronic granulation otitis media, 7 cases of cholesteatomous otitis media, 6 cases of malignant neoplasms and 21 cases of benign neoplasms. Post-opertive specimens like polyps, cholesteatoma masses, granulation tissues and malignant neoplasms tissues were subjected to PRC reaction.

Results: among all 53 cases HPV viral DNA was indentified in 22 cases (41.5%), 12 of them (22.6%) were high oncogenic HPV type 16 and 18, and 14 of them (26.4%) were low oncogenic HPV type 6 and 11. Detection of viral DNA in the group of 39 chronic granulation otitis media cases gave the result of 12 (22.6%) positive asssays for Papilloma DNA, 9 (16.9%) positive assays for HPV type 6 or 11, and 7 (13.2%) positive assays for HPV type 6 or 11. In the group of cholesteatomatous chronic otitis media analogous identification gave positive assays for HPV type 6 or 11 in 5 (70.5%). In each of 6 middle ear malignant neoplasms a presence of HPV type 16 or 18 was confirmed. A control study (a group of patients operated on otosclerosis and tympanic membrane perforation) was fully negative - in any case no HPV DNA was identified.

Conclusions: HPV type 6 and 11 are connected to benign lesions in middle ear, and HPV type 16 and 18 are strictly connected to malignant neoplasms. It is plausible, that its presence in middle ear tissues is one of the reasons for pathological growth within middle ear structures.

P19

In vitro study of the coupling load required for the otologics middle ear transducer MET

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Introduction: To assess the optimal static preloading of the Otologics´ Middle Ear Transducer (MET) ossicular stimulator, when coupled to the incus, we measured vibration patterns with Laser-Doppler vibrometry. The MET Ossicular Stimulator is a partially implantable electro-magnetic middle ear hearing device which transmits vibrations to the ossicular chain.

Materials and Methods: We used three human cadaveric temporal bones and one MET Ossicular Stimulator. Laser-Doppler vibrometry was used for temporal bone selections. After the bone selection we extirpated the cochlea from the posterior side in order to measure the vibrational patterns of the footplate. Three temporal bones with different vibrational patterns (VP) were selected based on data of a normal hearing population (N=110): one TB with a VP larger than + 1 S.D., one TB with a VP in the range of ± 1 S.D. and 1 TB with a VP smaller than - 1 S.D. Transfer functions between vibrational patterns of the coupling rod, umbo, incus and footplate measurement points were calculated. Afterwards we defrosted the temporal bones, implanted the middle ear transducer (MET), coupled it to the ossicular chain and measured different coupling loads at the incus, the umbo and footplate.

Results: Optimal transfer function between the MET-transducer and the oval window was possible during contact when the coupling rod advanced 0.0625 mm (90°rotation). Additional advances of 0.0625 mm (180°turn = 0.125 mm) resulted in a decreased vibrational amplitude between 20 to 40 dB below 3 kHz. The lowest linear distortion occurred up to 10 kHz during

direct contact without advancing the coupling rod. Conclusion: Based on our findings we are of the opinion that optimal force loading occurs between 0° (contact situation) and 0.0625 mm (90° rotation). For intraoperative usage we recommend an advancement of 0.0312 mm (45° rotation) in order to avoid an overloading. Overloading might result in a decreased efficacy of the MET.

P20

Influence of the cochlear implant electrode on the mechanical function of the inner ear

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Purpose: During the past years cochlea implantation (CI) has evolved to be the therapy of choice for the patient with profound hearing loss. The cochlea implant electrode stimulates directly the ending of the auditory nerve and therefore a functioning middle and inner ear is not necessary for hearing with the implant. However, it has been speculated that the auditory function of the inner ear might be important for the hearing impression in the patient with a cochlear implant. Therefore it is important to know how insertion of the electrode into the scala tympani of the inner ear influences the auditory function of the ear and especially the vibratory properties of the cochlea. In this study we assess the vibratory patterns of the round window as a measure for auditory function before and after insertion of the implant electrode.

Material and Methods: A laser beam will be aimed through a posterior tympanotomy onto the round window. A multi-sine tone will be generated and calibrated, and the scanning measurements of the round window vibration amplitude will be performed as a baseline using a scanning laser Doppler interferometer. Then the cochlea will be opened and the CI electrode will be inserted. The assessment of the round window vibrations will then be repeated. The study will include adult german speaking patients with profound bilateral hearing loss undergoing cochlear implantation. Children and patients with inner ear malformations will be excluded from this study. Prior to surgery all patients will be precisely informed and will have consented to participate in the study.

Results and Conclusion: First results are encouraging and show that the method is working and that data can be acquired during live surgery.

P21

Laser doppler velocimetric data in young normal hearing subjects

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Introduction: The aim of the study was to evaluate a modified laser Doppler vibrometer (LDV) and to establish a normative curve of the vibrational pattern of the umbo in normal hearing subjects.

Materials and Methods: A LDV (Model OFV-3001 with an OFV-302 sensor head, Polytec) coupled to an operative microscope (OPMI MDM, ZEISS) was used to evaluate umbo displacement at sound pressure levels of 60, 70 and 80 dB SPL at the umbo of 33 female and 22 male subjects with audiometrically proved normal hearing.

Results: The mean displacement curve can be devided in four regions for the frequency range 200 Hz - 7,1 kHz : a basstone plateau (P1), first resonantpoint (R1) with following roll-off (A1), a turningpoint (W) with following roll-up for female or with following plateau for male (P2), up to a second resonantpoint (R2); followed by a second roll-off (A2).

Conclusion: These references can be used for further measurements in the future for example to compare it with pathological situation of the ear. The small dispertion of the laseraudiometric results argue in favour of a reliable measuring instrument.

P22

Prognostic factors of chronic otitis media

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The goals of successful tympanoplasty are the removal of the underlying pathologic processes and the achievement of a mucosal-lined middle ear cleft with an intact tympanic membrane and sound-conducting mechanism. The prognostic factors can be divided into intrinsic factors: eustachian tube function, disease severity and status of residual ossicular chain, and extrinsic factors: surgical technique, staging, design and composition of the graft and prosthesis.
We reviewed the middle ear risk index (MERI) by Becvarovski and type of surgery in our patients. The risk factors of MERI index are otorrhea, perforation of tympanic membrane, cholesteatoma, ossicular status, granulation or effusion of middle ear, previous surgery and smoking.

Material and methods: It is retrospective study of 266 patients (157 male and 109 female) with chronic otitis media with or without cholesteatoma in department of Otolaryngology Pardubice between July1996 and December 2004. All patients underwent 310 surgeries, 15 patients were operated on both sides, 18 patients had two surgeries on one side, 4 patients three surgeries on one side and one patient four surgeries on one side. We distinguished the type of surgery: tympanotomy with resection of retraction pocket (10 cases), atticotympanotomy (58 cases), modified radical mastoidectomy (104 cases), radical mastoidectomy (9 cases), revision after mastoidectomy (48 cases) and simple cortical antromastoidectomy (10 cases) The follow-up period ranged from 1 to 9.5 years; mean 3.1 year.

Results: The risk factors of MERI and risk value were otorrhea: dry ear 33 cases, occasionally wet 157 cases, persistently wet 64 cases; perforation of tympanic membrane: none 121 cases, present 132 cases; cholesteatoma: none 87 cases, present 167 cases; ossicular status: normal 84 cases, defect of incus 79 cases, defect of incus and stapes 28 cases, defect of malleus 28 cases, defect of malleus, incus and stapes 34 cases; middle ear: normal mucosa 141 cases, granulations or effusion 112 cases; previous surgery none 185 cases, revision 64 cases; 196 nonsmokers and 58 smokers. Statistical analysis was performed.

Conclusion: The MERI index was calculated and compared with hearing level before and after surgery. We concluded patients with higher MERI index had worse preoperative and postoperative air-bone gap.

P23

Relative rate of otosclerosis among first and second degree relatives of otosclerotic patients referred to otolaryngology department of Isfahan medical university - Iran

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Objective: To determine incidence of otosclerosis(OS) among 1st and 2nd degree relatives of surgically proved otosclerotic patients .

Methods: A cross sectional study among 43 surgically proved otosclerotic patients was performed to determine positive family history of OS, and physical exam, tunning fork tests, and audiometry were performed in suspicious members. We also reviewed 85 medical sheaths of otosclerotic patients admitted between 1374-1382 in our department, for family history of OS.

Results: Among 15(of 43) otosclerotic patients with positive family history (34.88%) , 14 individuals of their first and second degree relatives had clinical and audiometric otosclerosis. Among 85 medical record sheaths of otosclerotic patients, 12 patients (27.9 %) had positive family history for OS.

Conclusions: The incidence of clinical and audiometric otosclerosis among first and second degree relatives of our otosclerotic patients is nearly similar to rate of positive family history of our patients. This incidence is relatively lower than other populations studied in other countries. Key words: Otosclerosis - family history - first and second degree relatives - hearing loss.

P24

An animal model of hearing loss in superior-canal dehiscence syndrome

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Purpose: Superior semicircular canal dehiscences (SCD) have been identified as a non-middle-ear cause of conductive hearing loss (e.g. Mikulec et al. Otol Neurotol, 2004; 25:121-129). The purpose of this study is to understand the mechanisms through which SCDs induce changes in auditory sensitivity to both air-conducted (AC) and bone-conducted (BC) stimuli.

Materials & Methods: We surgically introduced holes (dehiscences) into the superior semicircular canal (SC) of 32 chinchillas while monitoring cochlear potential (CP) in response to BC stimuli, and also monitoring CP, middle-ear input admittance (Yme), and stapes velocity (Vs) in response to AC stimuli. Also, an anatomically-realistic, lumped-element, mathematical model used to predict the effect of SCD on auditory responses to AC stimuli.

Results: The introduction of an SCD increased the sensitivity to BC stimuli by 8 dB (near 500Hz) and decreased sensitivity to AC stimuli by 8dB (near 500Hz), resulting in an air-bone gap of 16dB. Additionally, both Yme and Vs increased after SCD in response to AC sound. The AC results are consistent with the 'third-window' hypothesis, in which the SCD shunts stapes volume velocity away from the cochlea through the dehiscent canal resulting in decreased auditory sensitivity to AC stimuli and increases in Yme and Us. Our mathematical model quantitatively supports this hypothesis.

Conclusions: Superior canal dehiscence produces an air-bone-gap in an animal model by inducing both increased sensitivity of the ear to bone-conducted sound and decreased sensitivity to air-conducted sound. Dehiscence induced changes in middle-ear mechanics are consistent with the SCD shunt reducing the cochlear input impedance. [Work supported by NSF and NIDCD]

P26

Epidemiology of pressure regulation. Incidence of ventilation tube treatments and its preliminary correlation to subsequent ear surgery

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Purpose: Treatment with ventilation tubes (VT) in secretory otitis media and related condi-tions is a very common procedure based on the rationale of equilibrating the middle ear pres-sure (MEP) with ambient. Repeated VT treatments are also common in more severe cases, which associated with chronic otitis media and an increased the risk of permanent perforation of the tympanic membrane. The purpose of the present study was to described the current incidence VT treatments in children (<15 years) during 2000 to 2005 in a Danish County, and to analyse the number of these children later admitted to a tertiary hospital setting for subse-quent reconstructive ear surgery.

Materials and Methods: Database information was achieved from the County Health Au-thorities with information on all VT treatments in children in primary otological practices for the period. Cross reference of this information for year 2000 was made with our database on ear surgery for the identification of patients, who subsequently had been referred for surgery at our department.

Results: During the period of 2000 to 2005 the number of VT insertions was constant around 6000 per year corresponding to an incidence rate of 1200 per 100,000 inhabitants per year. One or more repeated VT's were found in 32 % of the children. The majority of children were 1-2 years old (37 %) with a minor predominance of boys (ratio 1.3). A total of 3218 children were treated with one or more VT's in 2000 corresponding to a prevalence of 3.5 %; in the following observation period 42 of these were identified in our department, where the major-ity had surgery in 2004 (31 %) and 2005 (19 %). A total of 45 surgical procedures were per-formed in these children: 38 myringoplasties (84 %), 4 tympanoplasty type II (10 %), 2 tym-panoplasty type III (4 %), and 1 mastoidectomy (2 %); cholesteatoma was found in 8 cases (18 %).

Conclusions: The occurrence of VT treatments was stable in the period of 2000 to 2005 with a prevalence of 3.5 % of children. In ⅓ of the children ≥2 VT were inserted. During our lim-ited period of 5 year follow up only few children (1.3 %) were submitted for ear surgery; the majority of children had simple myringoplasties performed (84 %) explained by the risk of permanent perforation, whereas more severe cases with structural damages consisted of 16 %. The numbers of children submitted for reconstructive surgery are low estimates of the epidemiological weight and clinical significance of MEP regulation, since our preliminary period of observation is short to this point.

P27

Morpho-functional Partition of the Middle Ear Cleft

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The middle ear cleft consists of the tympanic cavity and the mastoid gas cells system, which are connected to each other, and in which gas circulates and undergoes more or less important exchanges. These cavities have specific characteristics leading to particular function. We will show that the middle ear cleft is divided into two main parts by means of a true inter- attico-tympanic diaphragm, which separates the two parts by morphology as well as function. The antero-inferior compartment, situated under the diaphragm, includes the pro-, meso- and hypotympanum. It is covered by secretory, or non secretory, ciliated cells, usually with a muco-ciliary clearance function. It consists of a less rigid chamber because of the presence of the drum. Thanks to the fibrocartilaginous eustachian tube, it opens in an intermittently ventilated gas pocket. It communicates with the superior compartment by both of the two previously mentioned openings. It is probably the site of predilection of secondary bacterial infections from the rhinopharynx. An inflammatory process involving the mucosa of the antero-inferior middle ear compartment leads to muco-ciliary clearance problems, and to the accumulation of mucous, which could generate, among other things, serous or sero-mucous otitis. Additional infection is possible. A rare consequence could be tympanosclerosis. The postero-superior compartment, situated above the diaphragm, includes the epi- and retro-tympanum, aditus ad antrum, antrum and mastoid gas cell system. It is covered by a richly vascularised cuboidal epithelium, mainly devoted to gas exchange. It consists of a rigid chamber, and an open, non ventilated gas-pocket which communicates with the inferior compartment by way of both openings. It is probably the site of predilection of viral haematogenous infections. An inflammatory process involving the mucosa of the postero-superior middle ear compartment, causes problems in the exchange of gas, leading to the development of a tympanic membrane retraction pocket, which could eventually deteriorate into cholesteatoma.

P28

DPOAE following stapes surgery: Stapedectomy versus stapedotomy

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Introduction: Our study was designed to evaluate DPOAE following stapes surgery (SS) in patients with otosclerosis and to compare two surgical techniques that are currently being used for SS in our department.

Method: The study cohort included 12 males and 17 females aged between 16 and 69 years. DPOAE was recorded prior to and 1 month after surgery. Twelve patients underwent stapedectomy (SE) and the other 17 were operated on using stapedotomy technique (SO). Results: DPOAE were measured only in low frequencies in 2/12 patients in SE group and 5/17 patients in SO group prior to surgery. DPOAE were recorded post-operatively in all but 4 patients (2 in each group). The amplitude of post-operative DPOAE was significantly higher in SE group at frequencies 3, 4, and 5 kHz ($p<0.05$, <0.01 and < 0.001, respectively) and did not differ significantly at frequency 2 kHz between the two groups. Decreasing of the DPOAE amplitude was demonstrated in 3 patients (2 in SE and 1 in SO group) who reported again for follow-up examination 6-9 months after SS.

Conclusions: Our results could be explained by variations of changes of sound transmission properties related to different kinds of prostheses used for stapes replacement. Scar formation can compromise the mobility of the reconstructed ossicular chain and lead to decrease of DPOAE through the time.

P29

Stapesplasty: Comparison of conventional technique with CO2-laser-stapedotomy using single-shot technique

J. Rodriguez Jorge, MM. Maassen, HP. Zenner, Tübingen; Germany

Introduction: A recent question in laser-aided stapesplasty is whether there are inner ear damages after laser aided surgery. Different lasers have different characteristics depending on their wavelenght and therefore possibly different effects on the inner ear. Aim of this study was to investigate whether the CO2-Laser used in single shot technique does lead to a different frequency of inner ear damages in comparison to the conventional stapedotomy according to Fisch.

Material and Methods: We performed a retrospective chart investigation in a tertial referal center. The results of 183 CO2 -Laser aided stapedotomies according to Jovanovic were compared with 64 according to the conventional Fisch technique between 2001 and 2004. Parameters of the investigation were audiological results and postoperative complications. Results: Differences of audiological results and of the rate of complications did not reveal a statistical significance. Postoperative hearing results showed an improvement of 23 dB at 250 Hz up to 5 dB at 6000 Hz for both groups (t-Test 0,6-0,2). The incidence of sensorineural hearing loss was 6.5% (12 patients) in the laser group compared with 12.5 % (8 patients) with the conventional laser technique.

Conclusion: Similar good results can be obtained using either CO2 laser single-shot-technique or convential stapedotomy. ABG closure rate were analogous in the 2 techniques as well as in the complication rate.

P31

Histological assessment of the ossicular autografts used in Tympanoplasty

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Introduction: Many surgeons use different techniques for ossicular reconstruction In tympanoplasty Different types of autografts, homografts, xerografts and artificial prostheses have been tried to restore & correct the sound pressure transformer mechanism of the middle ear. The use of ossicular autografts in cholesteatoma as it is usually associated with bone erosion caused by osteoclast activation.

Purpose: This study was preformed to estimate the benefit and the safty of the use of ossicular remnants after removal of cholesteatoma matrix by subperiosteal skeletonization under the operating microscope.

Material and Methods: Twenty ossicles were obtained from cases of cholesteatomatous chronic supprative otitis media and 4 normal ossicles obtained from normal cadavers were included in this study. Cholesteatoma was removed from the ossicles by subperiosteal skeletonization under the operating microscope .The

twenty inflammed ossicles and the 4 normal ossicles were fixed,prepared and divided into 2 equal group for examination by scaning and transmission electronic Microscope

Results:
o Cholesteatoma matrix was limited and restricted to the surface of the bone of the ossicular remnant with no deep invasion
o In most of the ossicle examined inflammatory and bone reactions were observed only at the bone -submucosa contact zones. Only one case showed marked osteoclastic changes reaching the ossicular inner core
o Bone deposition was noticed in some ossicles denoting that bone repair went hand in hand with bone erosion

Conclusion: The subperiosteal skeletonization of the ossicular remnants under the operating microscope proved to be a meticulous method for complete cleaning of the Cholesteatoma matrix, rendering them safe autografts for hearing reconstruction during surgery provided that the Cholesteatoma matrix and all osteotic bone are eradicated totally from the middle ear cleft.

P32
Laser doppler vibrometry data of the Clip piston MVP
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Background: A new malleus handle prosthesis for malleo-vestibulopexy and revision stapedotomy has been developed at our departement and successfully used during the last five years. The piston prosthesis bears the CliP®-mechanism to facilitate attachment to the malleus handle and length and position can easily be adjusted intraoperatively with a movable hinge.

Objective: The study was devised to determine if the special developed hinge of the CliP Piston MVP causes a loss of sound transfer from the malleus grip to the vestibulum. Methods: A middle ear model was set up, consisting of a vibrator normally used in an active implantable hearing device with a metal arm in shape and dimension of an actual malleus handle, where the CliP Piston MVP was attached with the hinge bend to an angle of about 120°. The piston end of the prosthesis dipped in a hole of a plastic container filled with water simulating a piston hole in the footplate. The excitation level corresponded to more than 110 dB SPL for frequencies between 100 Hz - 10000 Hz. With a laser doppler vibrometer the movements were picked up at different spots in the area of the clip, the hinge and the piston.

Results: The overall characteristics of the transferfunction was practically identical (difference < 3dB). Additionally biphasic resonance peaks (5-10 dB) were observed around 1000 Hz. Discussion: Our results show very stable transfer properties over the frequency band. The noticed resonance peaks of 5-10 dB are very probably below significance level in clinical pure tone audiometry. This is in accordance with our experience from clinical practice.

Conclusion: The CliP Piston MVP provides good transfer characteristics from the malleus handle to the vestibulum

P33
Ossiculoplasty with titanium prostheses
M. Romer, M. Vorburger, A. Huber, Zurich; Switzerland

Objective: To determine the hearing results and the complication rate one year after ossiculoplasty with the Kurz titanium system

Material and Methods: A retrospective chart review of 82 procedures in 77 patients. Included in the study were 36 Aerial-TORP and 46 Bell-PORP between October 2001 and October 2004. The air and bone conduction thresholds as well as the complication rate were evaluated.

Results: The mean preoperative air bone gap (ABG) was 32,9 (+/-13,4)dB. 16 (+/-7,2) months postoperatively the average ABG was 17,6 (+/-11,8) dB. The extrusion rate was 3/82 (3,7%). In one case (1,2%) the prosthesis perforated the stapes footplate and was dislocated into the vestibule without significant sensorineural hearing loss. The tympanic membrane reperforation rate and the cholesteatoma recurrence rate was 3/82 (3,7%) and 1/82 (1,2%) respectively.

Conclusion: The Kurz titanium prosthesis system provides hearing success comparable with current ossiculoplasty studies and low complication rate.

P34
Long-Term Study of "Vibrant® Soundbridge" implantable hearing aids
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Nowadays implantable hearing aids are an indispensable part of modern otologic and audiologic clinics. In principle, an active prosthesis using appropriate signal processing is implanted in the middle ear system. In this way the recipients can achieve better acoustic recognition and improved speech perception while the auditory ear canal remains open. In this study 11 patients out of 49 patients, who received an implantable hearing device (Vibrant® Soundbridge MED-EL) at the Department of Otolaryngology of the Medical University of Hanover, are evaluated by means of a number of audiological tests. The postoperative observation time averages 6.3 years. The results indicate a median functional gain of 30 dB. In monosyllabic speech tests the patients were able to achieve a 27 % median improvement of speech intelligibility at 65 dB SPL with the Vibrant Soundbridge. The results of multifrequency tympanometry revealed that the Vibrating Ossicular Prosthesis (VORP) has no significant influence on the resonance frequency of the middle ear over a period of 6 years. Conclusion: If the criteria for patient recruitment are adhered to, implantable hearing devices yield a good hearing benefit and high qualified speech perception with more comfort.

P35

Testing a method for quantifying the output of implantable middle ear hearing devices

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Purpose: Implantable middle-ear hearing devices (IMEHDs) have been used over the last decade to aid hearing function in patients with hearing loss, and multiple IMEHDS either have been or are being developed for use in patients. A significant issue is that it is difficult to compare the performance of different IMEHD devices. In order to provide a testing standard, the Food & Drug Administration of the US government participated in the development and testing of a "standard practice" for quantifying IMEHD output (ASTM International F2504: Standard Practice for Describing System Output of Implantable Middle Ear Hearing Devices). This report describes tests of the utility of this practice.

Materials & Methods: Measurements of sound- and IMEHD-driven stapes velocity were made in prepared temporal bones using laser- Doppler vibrometry. Pre-implantation CONTROL measurements of sound-induced stapes velocity were compared with a NORMAL RANGE determined from a collection of stapes-velocity measurements made in temporal bones from laboratories throughout the world (Rosowski et al. ARO 2004). CONTROL measurements that did not fall within the NORMAL RANGE led to exclusion of the bone from further testing. After implantation with the IMEHD electrical- mechanical transducer, measurements of the electrically driven stapes velocity were compared with the sound-driven CONTROL measurements to compute the Equivalent Sound Pressure per electrical input to the IMEHD transducer.

Results: Measurements of Equivalent Sound Pressure were performed for two IMEHD devices. The means and standard deviations were computed from measurements in 5 NORMAL bones. In performing these tests several additional bones failed to meet the NORMAL RANGE criteria.

Conclusions: A "standard practice" has been demonstrated to determine quantitative descriptions of the efficacy of IMEHD electrical-mechanical transducers. [Supported by the US-FDA and various IMEHD manufactures]

Authors and Speakers

The authors are soley responsible for the content of these abstracts.

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