



MEMRO

MIDDLE-EAR MECHANICS IN RESEARCH AND OTOTOLOGY
FIFTH INTERNATIONAL SYMPOSIUM



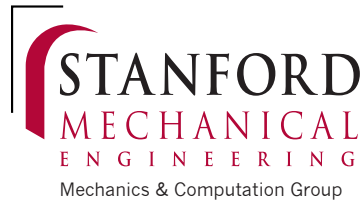
PROGRAM AND ABSTRACTS JUNE 24-28, 2009



Mechanics & Computation Group

<http://memro2009.stanford.edu>

Sponsors



June 24, 2009

Dear MEMRO Symposium Participants,

Welcome to Stanford University! On behalf of the Department of Mechanical Engineering and the Department of Otolaryngology–Head and Neck Surgery, we are delighted to have you join us for this year’s symposium on Middle Ear Mechanics in Research and Otology (MEMRO). We look forward to your participation in the events planned over the next few days, resulting in what are always lively discussions and rewarding interactions with colleagues. Please enjoy reconnecting with one another as well as meeting new friends. We have several who are joining us for the first time at MEMRO—a special welcome to all of you!

Best regards,



Sunil Puria, PhD
Program Chair



Charles R. Steele, PhD
Co-chair



Richard L. Goode, MD
Co-chair

Agenda

WEDNESDAY, JUNE 24, 2009

- 2:00 p.m. Registration opens
Annenberg Hall/Cummings Art Building
- 3:30–5:30 p.m. Tutorials
Building 420, Room 041
- 6:00 p.m. Bus to the welcome reception
- 6:30 p.m. Reception at the home of
Dr. Rodney and Sherry Perkins
- 8:30 p.m. Reception ends

THURSDAY, JUNE 25, 2009

- 8:00 a.m. Introduction and Keynote
Annenberg Hall/Cummings Art Building
- 9:00 a.m. ME Physiology
- 10:10–10:30 a.m. Coffee/Tea
- 10:30 a.m.–12:00 p.m. Passive Prosthesis I
- 12:00 p.m.–1:30 p.m. Lunch/Posters
Dohrmann Grove
- 1:30–3:00 p.m. Diagnostics I
- 3:00–3:20 p.m. Refreshments
- 3:20–4:45 p.m. ME Hearing Aids I
- 4:45–5:45 p.m. Posters
- 6:30 p.m. Night Out on the Town (Palo Alto)

FRIDAY, JUNE 26, 2009

- 8:00–10:15 a.m. Computational Models
Annenberg Hall/Cummings Art Building
- 10:15–10:35 a.m. Coffee/Tea
- 10:35 a.m.–12:00 p.m. Imaging Technologies
- 12:00 p.m.–1:30 p.m. Lunch/Posters
Dohrmann Grove

FRIDAY, JUNE 26, 2009, continued

- 1:30–3:00 p.m. Passive Protheses II
- 3:00–3:20 p.m. Refreshments
- 3:20–4:00 p.m. Panel Discussion
- 4:00–4:45 p.m. Posters
- 5:30 p.m. Bus to Winery
- 6:30 p.m. Winery/Dinner Banquet

SATURDAY, JUNE 27

- 8:30–10:20 a.m. Bone Conduction & High Noise
Annenberg Hall/Cummings Art Building
- 10:20–10:40 a.m. Coffee/Tea
- 10:40–11:29 a.m. Pressure Regulation
- 11:29 a.m.–12:30 p.m. Diagnostics II
- 12:30–2:00 p.m. Lunch/Posters
Dohrmann Grove
- 2:00–3:45 p.m. ME Hearing Aids II
- 3:45–4:05 p.m. Refreshments
- 4:05–4:50 p.m. Community Discussion
- 4:50–5:00 p.m. Poster awards and Closing Ceremony
- 5:00–7:00 p.m. BBQ dinner at New Guinea Garden

SUNDAY, JUNE 28

- 8:00 a.m.–8:00 p.m. Bus Excursion to Monterey

#	Title/Author(s)
P-1	Realistic morphological 3-D model of the gerbil middle ear, including bone and soft tissue structures <i>Jan A.N. Buytaert, Manuel Dierick, Patric Jacobs, Joris J.J. Dirckx</i>
P-2	Nonlinearity in eardrum vibration as a function of frequency and sound pressure <i>Johann R.M. Aerts, Joris J.J. Dirckx</i>
P-3	Active Middle Ear Implants (AMEIs) in Patients with Mixed or Conductive Hearing Losses – A Review and Analysis of the Literature <i>Mario D. Wolframm, Jane M. Opie, Christine Mühlöcker</i>
P-4	A clinical method for calibration of bone conduction transducers to measure the mastoid impedance <i>Reggie Weece, Jont B. Allen</i>
P-5	Micro-indentation to determine middle ear ossicles elasticity parameters <i>Joris A.M. Soons, Jef Aernouts, Joris J.J. Dirckx</i>
P-6	The new tool of ossicular mobility tester using an electromagnetic driver and a piezoelectric sensor <i>Daiki Takagi, Kiyofumi Gyo, Naohito Hato, Takeshi Iwakura</i>
P-7	Design and Implementation of Acoustic Sensor for Compensating Damping Effect of Skin using FEA simulation <i>Min Woo Kim, Ki Woong Seong, Hyung Gyu Lim, Eui Sung Jung, Jang Woo Lee, Dong Wook Kim, Myoung Won Lee, Jyung Hyun Lee, Jin Ho Cho</i>
P-8	Development of a Fully-Implantable Middle Ear Hearing Device in Korea <i>Jyung Hyun Lee, Ki Woong Seong, Eui Sung Jung, Hyung Gyu Lim, Min Woo Kim, Jang Woo Lee, Dong Wook Kim, Myoung Won Lee, Il Yong Park, Kyu Yup Lee, Sang Heun Lee, Jin Ho Cho</i>
P-9	Effect of absence of malleus on ossiculoplasty in human temporal bones <i>Yoshitaka Shimizu, Richard L. Goode</i>
P-10	Hearing improvement with laser contraction myringoplasty for tympanic membrane atelectasis <i>Naohito Hato, Daiki Takagi, Kiyofumi Gyo</i>
P-11	Contribution of static force and oscillator placement in bone conduction sensitivity <i>Lynn M. Brault, Woojae Han, Charissa R. Lansing, Ron D. Chambers, Jared McNew, Alessandro Bellina, Margaret Wismer, William D. O'Brien Jr.</i>
P-12	Our experience with the soft clip piston in stapedotomy <i>P.P. Singh, Arun Goyal</i>
P-13	Biomechanics of the new generation of stapesplasty pistons: efficiency of the self crimped incudo-prosthesis junction <i>N. Julian Holland, Antonio G. Miron, Dan Jiang, George Jeronimidis, Alec Fitzgerald O'Connor</i>

#	Title/Author(s)
P-14	Measurements of conductive hearing loss in mice <i>Zhaobing Qin, Melissa Wood, Suh-Kyung Lee, John J. Rosowski</i>
P-15	A new third window method for middle ear measurements in a human temporal bone model <i>Yoshitaka Shimizu, Sunil Puria, Richard L. Goode</i>
P-16	Different Kinds of Collagens in Tympanic Membranes <i>Johan Knutsson, Dan Bagger-Sjöbäck, Magnus von Unge</i>
P-17	Middle-ear Power Analysis in Patients with Conductive Hearing Loss <i>M. Patrick Feeney, Patricia Jeng, Lisa Hunter, Judi Lapsley Miler, Pierre Parent, Paul Boege</i>
P-18	Developing a non-surgical direct drive hearing device with an opto-electromagnetic actuator attached to the tympanic membrane: preliminary report <i>Tien-Chen Liu, Chia-Fone Lee, Chih-Hua Shih, Yuan-Fang Chou</i>
P-19	A Self-adjusting Ossicular Replacement Prosthesis <i>Eric W. Abel, Frank Abraham, Robert P. Mills</i>
P-20	Stapes Model: Two-layer annular ligament <i>Jong Dae Baek, Charles R. Steele, Sunil Puria</i>
P-21	The extended iPiston in stapedotomy: First clinical results <i>Daniel F. àWengen</i>
P-22	Feasibility study of Round Window Stimulation with the MET-V Implantable Middle Ear Device: a Temporal Bone Study <i>N. Julian Holland, Kanthaiah Koka, J. Eric Lupo, Daniel J. Tollin, Herman A. Jenkins</i>
P-23	Cochlear responsiveness to frequency-independent constant-velocity direct mechanical stimulation of the round window (RW) with the MET-V transducer <i>N. Julian Holland, Kanthaiah Koka, J. Eric Lupo, Herman A. Jenkins, Daniel J. Tollin</i>
P-24	Making Sense of Oval and Round Window Volume Displacement Asymmetry in Bone Conduction: A Third Window near the Round Window? <i>Namkeun Kim, Kenji Homma, Sunil Puria, Charles R. Steele</i>
P-25	A Comparison of the Non-linear Response of the Ear to Air and to Bone Conducted Sound <i>Odile H. Clavier, Jesse A. Norris, Anthony J. Dietz</i>
P-26	On the heating process of shape memory alloy prostheses <i>Albrecht Eiber, Alexander M. Huber, Michael Lauxmann</i>
P-27	Measurement of Nonlinear TM response by Scanning LDV <i>Mario Pineda, Jim Easter, David Mullin, Ben Balough</i>
P-28	Does Silastic Sheeting Over the Round Window Niche Affect Sound Transmission in the Human Middle Ear? <i>Wael A. Alian, Osama F. Majdalawieh, Manohar Bance</i>

WEDNESDAY, JUNE 24, 2009

Time		Title/Author(s)
2:00 p.m.		Registration Opens
	1	Tutorials Moderated by John J. Rosowski, Richard L. Goode
3:30 p.m.	1-1	Introduction to Otology: A surgical perspective <i>Karl-Bernd Hüttenbrink</i>
4:30 p.m.	1-2	Mechanics for the middle ear <i>W. Robert J. Funnell</i>
5:30 p.m.		Tutorials end
6:00 p.m.		Bus to the Welcome Reception
6:30 p.m.		Reception at the home of Dr. Rodney and Sherry Perkins
8:30 p.m.		Reception ends

THURSDAY, JUNE 25, 2009

Time		Title/Author(s)
8:00 a.m.		Introduction Sunil Puria, Robert K. Jackler, Peter M. Pinsky,
8:15 a.m.	2	Keynote Moderated by Charles R. Steele
	2-1	An evolutionary perspective on middle ears <i>Geoffrey A. Manley</i>
9:00 a.m.	3	ME Physiology Moderated by Peter M. Narins, Stefan Stenfelt
9:05 a.m.	3-1	A sum of simple and complex motions on the eardrum and manubrium in gerbil <i>Ombeline de la Rochefoucauld, Elizabeth S. Olson</i>
9:17 a.m.	3-2	Middle-Ear Pressure Gain and Cochlear Partition Differential Pressure in the Chinchilla <i>Michael E. Ravicz, Michaël C.C. Slama, John J. Rosowski</i>
9:29 a.m.	3-3	Effects of Spatial Stapes Excitations on Round Window Motion Patterns <i>Jae Hoon Sim, Michael Lauxmann, Christof Rösöli, Albrecht Eiber, Alexander M. Huber</i>
9:41 a.m.	3-4	On the effect of a dehiscence in the superior semicircular canal on hearing loss <i>Karl-Bernd Hüttenbrink, Dirk Beutner, Christoffer Lüers, Dirk Fürstenberg, Michael Lauxmann, Albrecht Eiber</i>
9:53 a.m.	3-5	Physiological Motions of the Stapes in Human and Guinea Pig Ears <i>Jae Hoon Sim, Michail Chatzimichalis, Michael Lauxmann, Christof Rösöli, Albrecht Eiber, Alexander M. Huber</i>
10:10 a.m.		Coffee/Tea
10:30 a.m.	4	Passive Prosthesis I Moderated by Kiyofumi Gyo, Susan E. Voss

THURSDAY, JUNE 25, 2009

Time	Title/Author(s)
10:35 a.m. 4-1	Interposition or tight fixation? Will a new Incus Replacement Prosthesis provide better sound conduction? <i>Daniel F. àWengen</i>
10:55 a.m. 4-2	Our new modular middle ear prosthesis concept <i>Thomas Beleites, Marcus Neudert, Matthias Bornitz, Irina Arechvo, Thomas Zahnert</i>
11:07 a.m. 4-3	A new TORP with a resilient joint: experimental data from human temporal bones <i>Irina Arechvo, Thomas Beleites, Nikoloz Lasurashvili, Matthias Bornitz, Thomas Zahnert</i>
11:19 a.m. 4-4	A Constant Tension Middle Ear Ossicular Replacement Prosthesis: Why Don't We Have One? <i>Richard L. Goode, Hiroyuki Yamada</i>
11:39 a.m. 4-5	A Novel Implant for Therapy of Non-aerated Middle Ears <i>Saumil N. Merchant, Michael E. Ravicz, Wade Chien, Stuart Montgomery, Michael Warren, Joseph B. Nadol, Jr., John J. Rosowski</i>
12:00 p.m.	Lunch / posters
1:30 p.m. 5	Diagnostics I Moderated by Thomas Zahnert, Willem F. Decraemer
1:35 p.m. 5-1	Detecting changes in intracranial pressure using emissions from the inner ear <i>Susan E. Voss, Nicholas J. Horton, Kevin N. Sheth, Modupe F. Adegoke, Jonathan Rosand, Christopher A. Shera</i>
1:55 p.m. 5-2	Wideband middle-ear muscle reflex test in a test battery to predict middle-ear dysfunction <i>Douglas H. Keefe, Denis F. Fitzpatrick, Yi-Wen Liu, Chris A. Sanford, Michael P. Gorga</i>
2:15 p.m. 5-3	What does acoustic reflectance tell us about the middle-ear? <i>Patricia S. Jeng, Jont B. Allen, Harry Levitt</i>
2:27 p.m. 5-4	Umbo and stapes vibration measurements reveal middle-ear pathology in aged guinea pigs <i>Diana Turcanu, Ernst Dalhoff, Andreas Heyd, Anthony W. Gummer</i>
2:39 p.m. 5-5	Stroboscopic holography Measurement of motion of human tympanic membrane: a preliminary study <i>Jeffrey Tao Cheng, Antti A. Aarnisalo, Ellery Harrington, Maria del Socorro Hernandez-Montes, Cosme Furlong, Saumil N. Merchant, John J. Rosowski</i>
3:00 p.m.	Refreshments
3:20 p.m. 6	ME Hearing Aids I Moderated by Daniel F. àWengen, Rong Z. Gan
3:25 p.m. 6-1	The EarLens System: New Sound Transduction Methods <i>Rodney Perkins, Jonathan P. Fay, Lisa Olson, Paul Rucker, Micha Rosen, Lee Felsenstein, Sunil Puria</i>

THURSDAY, JUNE 25, 2009

Time	Title/Author(s)
3:37 p.m. 6-2	Performance Considerations of Prosthetic Actuators for Round-Window Stimulation <i>Hideko Heidi Nakajima</i> , Saamil N. Merchant, John J. Rosowski
3:49 p.m. 6-3	Influence of FMT coupling parameters on vibration transmission to the round window <i>Andreas Arnold</i> , Christof Stieger, Claudia Candraia, Flurin Pfiffner, Martin Kompis, Rudolf Häusler
4:01 p.m. 6-4	Experimental investigations on the coupling of an active middle ear implant on the round and oval window niche <i>Thomas Zahnert</i> , Nikoloz Lasurashvili, Matthias Bornitz, Karl-Bernd Hüttenbrink
4:13 p.m. 6-5	The FMT positioning in the round window niche and its impact on hearing output in round window vibroplasty <i>Ranjeeta Ambett</i> , Roberta Marino, Brad Wood, Anne McArthur, <i>Gunesh P. Rajan</i>
4:25 p.m. 6-6	Electrocochleographic and Mechanical Assessment of Round Window Stimulation with the Implantable Middle Ear Hearing Device <i>Kanthaiah Koka</i> , N. Julian Holland, J. Eric Lupo, Herman A. Jenkins, Daniel J. Tollin
4:37 p.m. 6-7	Optimization of round window drive with the MET-V transducer with different interposed collagen materials <i>N. Julian Holland</i> , <i>Kanthaiah Koka</i> , J. Eric Lupo, Herman A. Jenkins, Daniel J. Tollin
4:42 p.m.	Session ends
4:45 p.m.	View odd-numbered posters
5:15 p.m.	View even-numbered posters
5:45 p.m.	End poster session
6:30 p.m.	Night out on the town (Palo Alto)

FRIDAY, JUNE 26, 2009

Time	Title/Author(s)
8:00 a.m. 7	Computational Models Moderated by Elizabeth S. Olson, Margaret G. Wismer
8:05 a.m. 7-1	On the mechanics of dehiscence in the superior semicircular canal <i>Albrecht Eiber</i> , Michael Lauxmann, Dirk Beutner, Karl-Bernd Hüttenbrink
8:17 a.m. 7-2	Evaluation of implantable actuators by means of a middle ear simulation model <i>Matthias Bornitz</i> , Nikoloz Lasurashvili, Hans-Jürgen Hardtke, Thomas Zahnert
8:29 a.m. 7-3	Wave model of the human tympanic membrane <i>Pierre Parent</i> , Jont B. Allen

FRIDAY, JUNE 26, 2009

Time	Title/Author(s)
8:41 a.m. 7-4	Towards high-realism physics based models of middle ear mechanics: high definition morphology, precise materials parameters and introduction of non-linearity <i>Joris J.J. Dirckx, Jef Aernouts, Johan Aerts, Jan A.N. Buytaert, Joris A.M. Soons</i>
9:01 a.m. 7-5	Finite-element modelling of the configuration changes of the ossicular chain with static pressure <i>Willem F. Decraemer, W. Robert J. Funnell, Stefan L.R. Gea, Jan A.N. Buytaert, Joris J.J. Dirckx</i>
9:21 a.m. 7-6	Nonlinear Stiffness Characteristics of the Ossicular Chain <i>Michael Lauxmann, Hans-Peter Zenner, J. Rodriguez Jorge, Albrecht Eiber</i>
9:33 a.m. 7-7	Measuring the quasi-static Young's modulus of the eardrum using indentation technique <i>S. Mohammad Hesabgar, Hanif M. Ladak, Abbas Samani, Sumit K. Agrawal</i>
9:45 a.m. 7-8	Quantification of tympanic membrane elasticity parameters from in situ measurements <i>Jef Aernouts, Joris A.M. Soons, Joris J.J. Dirckx</i>
9:57 a.m. 7-9	Middle-ear "gear" adaptation for high-frequency transmission <i>Sunil Puria, Charles R. Steele</i>
10:15 a.m.	Coffee/Tea
10:35 a.m. 8	Imaging Technologies Moderated by Alexander M. Huber, Michael L. Gaihede
10:40 a.m. 8-1	Rotational Tomography as a tool for quality control in reconstructive middle ear surgery (an experimental and clinical study) <i>Christian Offergeld, Karim Zaoui, Jan Kromeier, Nicoloz Lasurashvili, Thomas Beleites, Marcus Neudert, Matthias Bornitz, Roland Laszig, Thomas Zahnert</i>
11:00 a.m. 8-2	Reconstruction and Exploration of Virtual Middle Ear Models Derived from Micro-CT Datasets <i>Joseph Lee, Sonny Chan, Curt Salisbury, Kenneth Salisbury, Sunil Puria, Nikolas H. Blevins</i>
11:12 a.m. 8-3	Mastoid structural properties determined by imaging analysis of high resolution CT-scanning <i>Olivier Cros, Michael L. Gaihede, Magnus Borga, Orjan Smedby</i>
11:24 a.m. 8-4	In house developed navigated mechatronic system for implantable hearing devices <i>Christof Stieger, Marco Caversaccio, Andreas Arnold, Guoyan Zheng, Jonas Salzmann, Yves Mussard, Martin Kompis, Rudolf Häusler, Stefan Weber</i>

FRIDAY, JUNE 26, 2009

Time	Title/Author(s)
11:36 a.m. 8-5	Multiphoton and Electron Microscopy of Collagen in Ex Vivo, Human Tympanic Membranes <i>Ryan P. Jackson, Tony Ricci, Cara Chlebicki, Tatiana B. Krasieva, Reena Zalpuri, William J. Triffo, Sunil Puria</i>
12:00 p.m.	Lunch/Posters
1:30 p.m. 9	Passive Prosthesis II Moderated by Andreas Arnold, Irina Arechvo
1:35 p.m. 9-1	Extracellular bone matrix components on titanium prostheses induce osseointegration on the stapes footplate <i>Marcus Neudert, Thomas Beleites, Anne Kluge, Nikoloz Lasurashvili, Dieter Scharnweber, Thomas Zahnert</i>
1:47 p.m. 9-2	Microstructuring and bioactive nanolayer coating of titanium surfaces for middle ear ossicular replacement prosthesis <i>Justus Ilgner, Slavomir Biedron, Elena Fadeeva, Doris Klee, Martin Westhofen</i>
2:07 p.m. 9-3	Prosthetic Reconstruction to the Stapes Head or to the Stapes Footplate? A Laser Doppler Study <i>Wael A. Alian, Osama F. Majdalawieh, Rene G. Van Wijhe, Manohar Bance</i>
2:19 p.m. 9-4	Tight Stapes Prosthesis Fixation Leads to Better Functional Results in Otosclerosis Surgery <i>Alexander M. Huber, Jae Hoon Sim, Roman Laske, Dorothe Veraguth, Stephan Schmid, Thomas Roth, Albrecht Eiber</i>
2:39 p.m. 9-5	Malleovestibulopexy using titanium MVP clip piston <i>P.P. Singh</i>
3:00 p.m.	Refreshments
3:20 p.m. 10	Panel Discussion Moderated by Alexander M. Huber, Albrecht Eiber Panel Members: John J. Rosowski, Rodney Perkins, Samuel N. Merchant, Robert K. Jackler, Karl-Bernd Hüttenbrink, Kiyofumi Gyo, Rong Z. Gan, Nikolas H. Blevins
4:00 p.m.	View Posters
4:45 p.m.	End Poster Viewing
5:30 p.m.	Bus To Winery
6:30 p.m.	Winery/Dinner Banquet

SATURDAY, JUNE 27, 2009

Time	Title/Author(s)
8:30 a.m. 11	Bone Conduction and High Noise Moderated by Albrecht Eiber, Douglas H. Keefe
8:35 a.m. 11-1	Effect of the stapedius reflex on air conduction and bone conduction transmission in the human <i>Stefan Stenfelt</i>

SATURDAY, JUNE 27, 2009

Time	Title/Author(s)
8:47 a.m. 11-2	Experimental Validation of a Computational Model of Bone-Conducted Sound Transmission <i>Odile H. Clavier, Jesse A. Norris, Jed C. Wilbur, Ken J. Cragin, Anthony J. Dietz, Margaret G. Wismer, William D. O'Brien</i>
8:59 a.m. 11-3	Simulation of bone conducted sound pathways to the outer and middle ear <i>Margaret G. Wismer, William D. O'Brien</i>
9:11 a.m. 11-4	Acousto-elastic integral equation based numerical simulation tools for analysis of mechanisms of energy transfer to the middle ear and for high-noise protection device design <i>Elizabeth H. Bleszynski, Marek Bleszynski, Thomas Jaroszewicz</i>
9:23 a.m. 11-5	Effects of ear-canal pressurization on middle-ear responses for bone and air conduction <i>Kenji Homma, Yoshitaka Shimizu, Namkeun Kim, Yu Du, Sunil Puria</i>
9:43 a.m. 11-6	Failure analysis as tool for middle-ear research <i>Gerald Fleischer</i>
9:55 a.m. 11-7	Ultrasound transmission and behavioral tuning in the middle ears of Asian frogs <i>Marcos Gridi-Papp, Victoria S. Arch and Peter M. Narins</i>
10:20 a.m.	Coffee/Tea
10:40 a.m. 12	Pressure Regulation Moderated by Dirk Beutner, Richard L. Goode
10:45 a.m. 12-1	Middle ear pressure regulation - Complementary action of the mastoid and Eustacian tube <i>Michael L. Gaihede, Joris J.J. Dirckx, Henrik Jacobsen, Jef Aernouts, Morten Søvsø, Kjell Tvetærås</i>
10:57 a.m. 12-2	Connectivity Analysis of Suggestive Brain Areas Involved in Middle Ear Pressure Regulation in Humans <i>Saber Sami A.K., Michael L. Gaihede</i>
11:17 a.m. 12-3	Exchange of CO ₂ in the middle ear: Is it limited by perfusion or by diffusion? <i>Yael Marcusohn, Joris J.J. Dirckx, Amos Ar</i>
11:29 a.m. 13	Diagnostics II Moderated by Joris J.J. Dirckx, W. Robert J. Funnell
11:34 a.m. 13-1	Differential diagnosis using forward and reverse transfer functions: Measurements and Models <i>Ernst Dalhoff, Diana Turcanu, Hans-Peter Zenner, Anthony W. Gummer</i>
11:54 a.m. 13-2	Oval and round window assessment during cochlear implantation <i>Sharouz Bonabi, Daniel Bodmer, Albrecht Eiber, Norbert Dillier, Dorothe Veraguth, Alexander M. Huber</i>
12:06 p.m. 13-3	The effects of ossicular chain pathology and cartilage placement on the tympanic membrane to the motion of the tympanic membrane evaluated with time-averaged holography <i>Antti A. Aarnisalo, Jeffrey T. Cheng, Michael E. Ravicz, Cosme Furlong, Saumil T. Merchant, John J. Rosowski</i>

Program

SATURDAY, JUNE 27, 2009

Time	Title/Author(s)
12:18 p.m. 13-4	Measures of the Auditory Conductive Mechanism for High Frequencies <i>Gerald R. Popelka, Goutham Telukuntla, Sunil Puria</i>
12:30 p.m.	Lunch/Posters
2:00 p.m. 14	ME Hearing Aids II Moderated by Thomas Beleites, Jin Ho Cho
2:05 p.m. 14-1	Comparison of the frequency response of acoustic and implantable hearing aids <i>Hannes Seidler, Matthias Bornitz, Nikoloz Lasurashvili, Thomas Zahnert</i>
2:17 p.m. 14-2	A Middle Ear Implant Using a Piezoelectric Stack with Mechanical Amplification <i>Eric W. Abel, Robbie C. Brodie, Zhigang Wang, Robert P. Mills, Duncan J. Bowyer</i>
2:29 p.m. 14-3	The application of the fully implantable Carina system in patients with atresia auris congenita <i>Stefan Mattheis, Carolin Neumann, Ralf Siegert</i>
2:41 p.m. 14-4	TORP-Vibroplasty—experimental evaluation and clinical results <i>Dirk Beutner, Jan-Christoffer Luers, Matthias Bornitz, Thomas Zahnert, Karl-Bernd Hüttenbrink</i>
2:53 p.m. 14-5	Development of an implanted bone-conduction hearing aid using giant magnetostrictive material <i>Takuji Koike, Kensei Yamamoto, Michihito Aoki, Kyoji Homma, Naohito Hato, Sho Kanzaki</i>
3:05 p.m. 14-6	A totally implantable hearing system—TIHS <i>Rong Z. Gan, Chenkai Dai, Xuelin Wang, Don Nakmali, Mark W. Wood</i>
3:17 p.m. 14-7	The application of the fully implantable Carina system in patients with moderate to severe sensorineural hearing loss <i>Carolin Neumann, Stefan Mattheis, Ralf Siegert</i>
3:29 p.m. 14-8	Long-term follow up study of Rion implantable hearing aid <i>Kiyofumi Gyo, Naohito Hato, Masahiro Komori, Naoaki Yanagihara</i>
3:45 p.m.	Refreshments
4:05 p.m. 15	Community Discussion Moderated by Karl-Bernd Hüttenbrink, Stefan Stenfelt
4:50 p.m.	Poster Awards and Closing Ceremony
5:00 p.m.	BBQ dinner at New Guinea Garden
7:00 p.m.	BBQ ends

SUNDAY, JUNE 28, 2009

Time	Title/Author(s)
8:00 a.m.	Bus Excursion To Monterey
8:00 p.m.	Return from Excursion

1 TUTORIALS

Moderators: John J. Rosowski, Richard L. Goode

1-1 Introduction to Otology: A surgical perspective

Karl-Bernd Hüttenbrink

Affiliation: Dept. of ORL University clinic, Cologne, Germany

ABSTRACT

The presentation will explain the interest of otosurgeons in the collaboration with scientists and engineers for improving the acoustical outcome of their middle-ear surgery.

The development of materials that are tolerated by the biological system in the middle ear is a prerequisite for any discussion on mechanical properties. Even an acoustically perfect reconstruction will fail if the middle ear does not accept the material of the reconstruction or the prostheses. Considering modern life expectancy, biological tolerance of materials has to cover 80 years, for consideration of a prosthesis implanted in a young child.

The acoustical performance is related to the material only to a lesser extent. The reconstruction of the ossicular chain requires a stiff and hard material. For the reconstruction of the tympanic membrane, a compliant but solid material is required, in order to respond to the molecule-sized amplitudes of the hearing vibrations and to withstand the million times larger changes of ambient atmospheric pressures. Therefore, cartilage in various applications has become the preferred material for tympanic membrane reconstruction in complicated ear surgery cases. As for the design of prostheses for reconstruction of the ossicular chain, they should reproduce the biological function of the ossicular chain: transport of sound in hi-fi quality without significant loss or distortion, and, on the other hand, stability against the huge displacements as induced by ambient atmospheric air pressure variations. Therefore, new attempts are made to include joint-like structures in the reconstructed transmission line. Many other factors for optimal design of the prostheses are under research nowadays for optimizing the acoustic quality. The surgical handling of the prostheses with their delicate and intricate designs, is a further issue. The tiny dimensions of the prostheses and their components, as compared to the tremor and exactness of surgical maneuvers, have to be considered. This concern applies not only for passive, but especially for the new concept of active prostheses, the implantable hearing aids. Engineer-aided developments must not become too complicated in respect for the difficulty and duration for the surgical implantation. Many other aspects have to be considered for the integration of modern devices and future developments for the restoration of middle-ear function, like feedback-problems in active implants, stability of fixation points in the middle ear,

etc. Only the close cooperation between theoretical science and clinical experience can guarantee a successful approach and avoid damage to patients due to inadequate respect for the manifold influences to middle-ear function. (60 min.)

1-2 Mechanics for the middle ear

W. Robert J. Funnell

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ABSTRACT

The behaviour of the middle ear occurs on time scales from tens of microseconds to tens of seconds; includes spatial patterns of three-dimensional displacements ranging from nanometers to millimeters; and involves gas, liquid and several types of solid. Quantitative understanding of this behaviour is important in the quest for improved diagnosis and therapy. In this tutorial we present some of the relevant principles of mechanics and acoustics.

We introduce the concept of input/output linearity and then describe geometric and material non-linearities. We discuss low-frequency responses, touching on the complications of non-uniformity, inhomogeneity and anisotropy, and then discuss higher-frequency vibrations, including the effects of inertia and damping. We describe some aspects of visco-elastic behaviour, including relaxation, creep and hysteresis. Finally, we introduce different approaches to mathematical modelling of mechanical systems, including the distinctions between lumped and distributed, between analytical and numerical, and between black-box and structural, with particular attention to the finite-element method. (60 min.)

2 KEYNOTE

Moderator: Charles R. Steele

2-1 An evolutionary perspective on middle ears*

Geoffrey A. Manley

Affiliation: Dept. of Zoology, Technische Universitaet Muenchen, Germany

ABSTRACT

The traditional view that a true middle ear developed when vertebrates made the transition from fish in water to land-living animal has long since shown to be dramatically wrong. In fact, middle ears with a large tympanum and connected by one or more ossicles to the cochlea generally developed very much later in evolutionary history. In addition, tympanic middle ears developed over long periods of time independently, in a large number of

vertebrate lineages - many now extinct - and at least five times in lineages that still exist. The mammalian middle ear is different to all others and is not an “improved” single-ossicle middle ear. Rather, it is a radical and almost accidental new development that owes its origin more to changes in feeding patterns than it does to hearing. It happened to transmit higher-frequency sounds better than do single-ossicle middle ears and thus paved the way for the origin of the extremely high upper-frequency hearing limits of some mammals. The physiology of inner and middle ears being strongly dependent on the physical nature and size of their structures has meant that many features of sound perception and -localization have changed in accordance with animal size, in parallel with other changes associated with, for example, an increase in brain size. This paper presents one view of the evolutionary changes in middle-ear systems of vertebrates and presents a historical perspective on these remarkably simple and yet highly effective structures. (45 min.)

3 ME PHYSIOLOGY

Moderators: Peter M. Narins, Stefan Stenfelt

3-1 A sum of simple and complex motions on the eardrum and manubrium in gerbil*

Ombeline de La Rochefoucauld, Elizabeth S. Olson

Affiliation: Columbia University

ABSTRACT

Based on comparisons of ear canal and scala vestibuli pressures the gerbil middle ear transmits sound with a gain of ~25 dB that is almost flat with frequency, and with a delay-like phase corresponding to a 25 – 30 μ s delay. How the middle ear is able to transmit sound with such high temporal and amplitude fidelity is not known, and is particularly mysterious given the complex motion the ossicles and tympanic membrane (TM) are known to undergo. To explore this question, we looked at the velocities of the manubrium and along a line on the TM. The TM motion was complex, and could be approximated as the combination of a wave-like motion and a back-and-forth piston-like motion. The manubrium underwent bending at some stimulus frequencies and therefore its motion was not like a rigid body. It had a complex motion with frequency fine structure that seemed likely to be derived from resonances on the drum-like TM. (12 min.)

3-2 Middle-Ear Pressure Gain and Cochlear Partition Differential Pressure in the Chinchilla*

Michael E. Ravicz^{1,2}, Michaël C.C. Slama^{1,3}, John J. Rosowski^{1,2,3}

Affiliation: 1) Eaton-Peabody Laboratory, Dept of Otolaryngology, Massachusetts Eye and Ear Infirmary, Boston, MA; 2) Department of Otology and Laryngology, Harvard Medical School, Boston, MA; 3) Harvard/MIT Division of Health Sciences and Technology, MIT, Cambridge, MA

ABSTRACT

Our long-term goal is to describe the effects of inner-ear impedance and pathologies on middle- and inner-ear mechanics using an animal model (chinchilla) that has been used successfully as a model for the effects of semicircular canal dehiscence (SCD) on middle-ear function. An important step is to quantify middle- and inner-ear function in the normal ear. We present measurements of middle-ear pressure gain G_{mep} and trans-cochlear-partition differential sound pressure dP_{cp} in chinchilla derived from measurements of intracochlear sound pressures in scala vestibuli P_{sv} and scala tympani P_{st} and ear-canal sound pressure near the tympanic membrane P_{tm} over a wide frequency range. P_{sv} and P_{st} were measured with fiber-optic pressure sensors introduced through small holes near the oval and round windows. The small size (170 micrometer diameter) of the sensors helps minimize variations in sound pressure and damage to the cochlea during measurements.

The measured P_{sv} and computed G_{mep} are similar to previous estimates in chinchilla at stimulus frequencies between 300 Hz and 5 kHz but are different at other frequencies. Our P_{sv} and G_{mep} are similar to previous estimates in other animals and extend chinchilla results to higher frequencies. P_{st} and dP_{cp} show features similar to those seen in human temporal bones. The relationship between our dP_{cp} and cochlear potential in previous studies in chinchilla and other species provides a stronger link between inner-ear macromechanics and hearing. The chinchilla may be a useful animal model for exploring the effects of inner-ear pathologies such as SCD on cochlear mechanics. (12 min.)

3-3 Effects of Spatial Stapes Excitations on Round Window Motion Patterns

Jae Hoon Sim¹, Michael Lauxmann², Christof Rösli¹, Albrecht Eiber², Alexander M. Huber¹

Affiliation: 1) Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital of Zurich, Zurich, Switzerland; 2) Institute of Engineering and Computational Mechanics, University of Stuttgart, Stuttgart, Germany

ABSTRACT

Hypothesis: Spatial stapes motions determine round window motion patterns. *Background:* Round window motions have been measured using Laser Vibrometry, but their relations to the elementary components of stapes motions have not been fully investigated. This plays an important role when the stapes motions contain large portion of rocking components, especially in reconstructed ears. *Methods:* The stapes of guinea pigs is driven in each of its elementary motion components, i.e. piston-like and two rocking motions, by a custom-made magnet-coil drive system. It consists of a micron-size permanent magnet and three independent coils differently positioned from the magnet respectively. Using 3D Laser Vibrometer and Scanning Laser Vibrometer, the spatial motions of the stapes and the motion patterns of round window are measured. The laser beam angulations are precisely corrected with micro-CT images. By the same way, reconstructed ears with stapes piston prostheses are investigated. *Results:* In all measured specimens, the volume displacements and the mode shapes at the round window are dependent on spatial motions of the stapes and the driving frequencies. Impacts of the piston motions on round window motion patterns in reconstructed ears are similar to impacts of the stapes motions in normal ears. *Conclusions:* Volume displacement of the round window motion is mainly related to the piston-like stapes motion and the motion patterns strongly to the frequencies of excitation. The larger magnitudes of piston-like motions in guinea pigs as compared to human are compensated by smaller footplate area resulting in similar volume displacements. Measurements of the volume displacements at the round window can provide a methodology to evaluate prostheses in reconstructed ears. (12 min.)

3-4 On the effect of a dehiscence in the superior semicircular canal on hearing loss

Karl-Bernd Hüttenbrink¹, Dirk Beutner¹, Christoffer Lüers¹,
Dirk Fürstenberg¹, Michael Lauxmann², Albrecht Eiber²

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ABSTRACT

Background: Observations in the clinical practice and published data show different implications of a dehiscence in the upper semicircular canal with a different extent of hearing loss. *Hypothesis:* The objective of this study is to investigate the effects of a 3rd inner ear window on the dynamical behavior of the ossicular chain in the middle ear as the input to the fluid system. *Materials and Methods:* Temporal bones were prepared and holes were drilled of different sizes into the upper semicircular canal. A specific adapter was attached which allowed to connect a fluid column of variable volume and pressure representing the situation in the cranial compartment. As input to the inner ear, the spatial motions of the stapes were measured using a contactless Scanning Laser Vibrometer (SLDV) as well as a 3D Laser Vibrometer LDV. The sound pressure in the inner ear was measured via a microphone in the round window. *Results:* The effect on hearing loss of a dehiscence in the superior semicircular canal could be quantified depending on the size and location of the hole as well as on the volume and pressure of the cranial compartment. *Conclusions:* Evaluating the measurements potential mechanisms of a 3rd inner ear window could be derived and their impacts on the spatial motions of the stapes became clearer. (12 min.)

3-5 Physiological Motions of the Stapes in Human and Guinea Pig Ears

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Christof Röösl¹, Albrecht Eiber², Alexander M. Huber¹

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ABSTRACT

Hypothesis: The complex stapes motions between human and guinea pig ears differ. The complex stapes motions can be quantitatively assessed and its error boundaries can be defined. *Background:* It has been reported that the motion of the stapes in response to acoustic stimulation is mainly piston-like along the longitudinal axis of the stapes at low frequencies. However, at higher frequencies, it contains rocking motions around the long and short axes of the footplate in the human and animal ears. *Materials and Methods:* Six human temporal bones from human cadavers and six guinea pig ears are used for

comparison of the complex stapes motions between two species. To describe motions of the stapes, a motion component in a specific direction is measured at multiple points on the footplate using a laser vibrometer scanning system and elementary components of complex stapes motions calculated from the measurements. The direction of the laser beam and coordinates of measurement points on the footplate plane are calculated by correlation between the measurement frame and the stapes-fixed frame, which is obtained from micro-CT scan. *Results:* The ratios of the rocking motions relatively to the piston-like motion of the stapes show larger values in human ears than ones in guinea pig ears. *Conclusions:* Differences of stapes motion between two species are presumed to be caused by differences in middle-ear anatomy. Alignment of the stapes can be exactly obtained using micro-CT imaging. Errors in the measurement and their impacts on the motion components of the stapes are within reliable range. (12 min.)

4 PASSIVE PROSTHESES I

Moderators: Kiyofumi Gyo, Susan E. Voss

4-1 Interposition or tight fixation? Will a new Incus Replacement Prosthesis provide better sound conduction?

Daniel F. àWengen

Affiliation: University Hospital of Basel, Switzerland

ABSTRACT

Introduction: Incus defects are among the most common causes for sound conduction impairment. Reconstruction with PORP does not reproduce the anatomical pathway from malleus to stapes. *Objectives:* The novel Incus Replacement Prosthesis IRP uses three ball-joint angulations to allow placement in all anatomical variations of any missing incus. A clip attaches to the malleus handle and a newly designed clip to the stapes suprastructure. The three articulations imitate the physiological function of the incus. Unlike to any PORP this IRP truly connects the Malleus to the stapes. *Results:* Laser Doppler measurements show improved sound conduction. First clinical experiences with this IRP are scheduled for end of 2008/ beginning 2009. *Discussion and Conclusion:* This new IRP might be able to reproduce the human incus by bridging the malleus to the stapes. Due to the three ball-joints this multi-variable prosthesis adapts to various sizes of middle ears. Further clinical studies will have to confirm these preliminary results. (20 min.)

4-2 Our new modular middle ear prosthesis concept

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ABSTRACT

Background: Dislocations and extrusions of TORP's are complications after middle ear surgery because of larger ear drum movements in static pressure changing. To solve the Problem some authors suggest different possibilities like flexible TORP or cartilage punch. To combine the advantages of prosthesis fixation and length variability we developed a new Concept for total ossicular chain reconstruction. *Materials and Methods:* Special titanium parts were implant in sheep stapes footplate and after 3 month investigated with micro-CT and histological proceeding. Sound transmission of some alternative designed prostheses was measured in fresh temporal bone with Laser Doppler Vibrometry. The micromechanical joint was measured with a load cell. Functional aspects of these prostheses were also calculated in a Finite Element Model (FEM). *Results:* Our Investigations for titanium implants on the footplate in sheep shows the possibility for bony integration. Measurements of joint prostheses find comparable sound transmission to intact ossicular chain. The bending forces of the micromechanical joint depended on the silicone stiffness and correlated closely with the point of exposure. TORP with spring element shows loss in conduction. Calculations in FEM show good sound transmission in stiff prostheses and poor transfer characteristics in soft models. The ball cup coupling gives the impression of a stabile and flexible connection. *Conclusions:* The bony integration from titanium implants on the stapes footplate allows the implantation of a small anchorage part in first time operation. Using this fixation point and implant the resilient joint TORP, it's possible to create a stable, self length adjusting reconstruction in the second time operation. So we can demonstrate a save and high quality transmission prosthesis system. (12 min.)

4-3 A new TORP with a resilient joint: experimental data from human temporal bones

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ABSTRACT

Background: Prosthesis dislocations and extrusions are frequent complications after middle ear surgery in case of chronic tubal dysfunction. The flexible avian columella works successfully under changing static conditions. That's why it can represent the model of a new TORP design. The creation of the flexible implant with self-adjusted length properties was considered as a valid approach to the problem of compensation of static eardrum displacements. **Materials and Methods:** A new prosthesis consists of two titanium shafts which are incorporated into the silicone body. Two silicones of different hardness were investigated experimentally. Sound transfer function and static performance of the prostheses were evaluated in fresh human temporal bones using laser Doppler vibrometry. The bending forces and behavior of the prostheses under simulated compression have been also investigated. **Results:** Sound transfer characteristics of the prostheses under uncompressed condition were comparable with those of an intact ossicular chain. Under the compression the implant with the softer silicone had the better acoustical transfer characteristics. In static experiments the minimal medial footplate displacements were found with same implant, containing the softer silicone. Conversely, the larger stapes footplate force was observed when applying prosthesis with the stiffer silicone, but still the footplate displacements were smaller than in case of reconstruction with conventional TORP. Simulating compression of the prostheses the bending forces depended on the silicone stiffness and correlated closely with the point of exposure. **Conclusions:** The investigated titanium prosthesis with a resilient joint features excellent sound transfer characteristics under normal condition. It also shows good transfer quality under the compression. Due to joint bending the implant follows large eardrum excursions which are not entirely transmitted to the inner ear. Therefore the new implant effectively reproduces both middle ear functions: sound conduction and protection of the inner ear. **Funding Source:** DAAD. (12 min.)

4-4 A Constant Tension Middle Ear Ossicular Replacement Prosthesis: Why Don't We Have One?

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ABSTRACT

Hypothesis: The role of prosthesis tension in providing optimal middle ear ossicular reconstruction hearing results following otologic surgery has been well studied in human temporal bone experiments. The evidence is very strong that there is an optimal replacement prosthesis tension between the tympanic membrane (TM) or malleus and the stapes head or footplate. The difficulty lies in quantitating the tension at the time of surgery and currently this is based solely on clinical experience. The length of the replacement prosthesis is critical—too long and low frequency sound transmission is decreased while too short, higher frequency transmission is affected. A prosthesis that provides a constant tension, independent of the distance between its outer and inner contact points would solve this problem and eliminate the learning curve of determining optimal tension for the otologic surgeon, plus provide more consistent and better post-operative hearing results.

Background: This review will be based on over 20 years experience of the senior author attempting to develop such a prosthesis plus the experience of other otologists, including a literature review. A constant tension spring incorporated within the prosthesis, in theory, should produce the desired results. It would also adjust for post operative variations in TM/malleus to stapes head or FP distances, something not possible with current prostheses. Other methods are possible besides a constant tension spring but why, despite a plethora of prostheses, is such a prosthesis unavailable? *Materials and Methods:* Using a fresh human temporal bone model, constant tension prototypes designed with the help of the Stanford Mechanical Engineering Department were tested. Sound transmission based on stapes footplate displacement measurements using a Polytec HLV 1000 laser vibrometer was measured before and after replacement of the incus and incus-stapes with a variety of constant tension spring containing prostheses. Input at the TM was 80 dB SPL over the frequency range 0.1 to 10 kHz using a computer generated sound system (SYSid 6.5 System). Comparison was made with the same spring inactivated at atmospheric and + 10 and +20 mm. Hg pressures in the ear canal to mimic the commonly seen post-operative inward movement of the TM and malleus. *Results:* The constant tension prostheses did function better than a standard prosthesis at positive ear canal pressures but were significantly worse than standard prostheses (inactivated spring) at atmospheric pressures, particularly at lower frequencies, because of vibration absorption by the spring. While this could be

minimized, it could not be eliminated. *Conclusion:* While appearing simple in concept, this does not appear to be the case. The goal of this paper is to allow others to learn from our experience so we can solve the problems and develop such a prosthesis. (20 min.)

4-5 A Novel Implant for Therapy of Non-aerated Middle Ears

Saumil N. Merchant^{1,2,3}, Michael E. Ravicz^{1,2}, Wade Chien^{1,2},
Stuart Montgomery⁴, Michael Warren⁴, Joseph B. Nadol, Jr.^{1,2,3},
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ABSTRACT

Hypothesis: Our goal is to develop a middle-ear “balloon” implant to restore hearing in non-aerated ears by producing a permanent air pocket within the middle ear. The implant is designed to be placed between the tympanic membrane and the promontory/round window. The introduction of such a compressible pocket would restore hearing by allowing sound-induced motion of the tympanic membrane, ossicles and round window. The implant would be indicated in patients with chronic otitis media and a conductive hearing loss due to non-aeration of the middle ear. *Background:* Previous studies have shown that a small amount of air can facilitate middle-ear function in human temporal bones and hearing in patients with fluid-filled middle ears. A successful middle ear balloon implant must possess the following requisite characteristics: 1) Barrier properties: impermeable to air and body fluids, thereby allowing it to remain inflated for long time periods. 2) Acoustic properties: compressible by sound vibrations. 3) Biocompatibility: non-toxic and not biodegradable by the host response of the middle ear. *Material and Methods:* Prototype implants (5x3x2 mm) comprising a thin biocompatible polymeric wall enclosing an air volume of 20 microliters were fabricated. *Results:* 1) Bench testing showed stable barrier properties under continuous immersion in saline for over 30 months. 2) Acoustic admittance measurements demonstrated that the balloons had equivalent air volumes between 50 and 90% of their physical volumes. In cadaveric temporal bones, in which filling the middle ear with saline produced a 30–35 dB decrease in umbo velocity, introducing balloon implants restored umbo velocity. The improvement in umbo velocity was roughly proportional to the total equivalent volume of the implants. 3) Implantation of balloons in chinchilla middle ears has shown no evidence of a host response or toxicity after six months. *Conclusion:* The middle-ear balloon implant may be a viable treatment for conductive hearing loss due to non-aeration of the middle ear. *Funding:* Work supported by NIDCD, Boston Medical Products, and donations to the MEEI. (20 min.)

5 DIAGNOSTICS I

Moderators: Thomas Zahnert, Willem F. Decraemer

5-1 Detecting changes in intracranial pressure using emissions from the inner ear*

Susan E. Voss^{1,3,4,5}, Nicholas J. Horton², Kevin N. Sheth³,
Modupe F. Adegoke¹, Jonathan Rosand³, Christopher A. Shera^{4,5,6}

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ABSTRACT

Intracranial pressure (ICP) monitoring is currently an invasive procedure that requires access to the intracranial space through an opening in the skull. Noninvasive monitoring of ICP via the auditory system is theoretically possible because changes in ICP transfer to the inner ear through connections between the cerebral spinal fluid and the cochlear fluids. In particular, low-frequency distortion-product otoacoustic emissions (DPOAEs), measured noninvasively in the external ear canal, appear to depend on intracranial pressure. Postural changes in healthy humans cause systematic changes in ICP. Here, we discuss the effects of postural changes, and presumably ICP changes, on DPOAE magnitude and phase. In general, DPOAE magnitudes decrease with increased ICP at frequencies between 500 to 1500 Hz, and the corresponding phase shows systematic changes in a given individual. We will also discuss preliminary results related to the measurement of DPOAEs on patients undergoing medically necessary ICP monitoring, which demonstrate that repeated measurements on this population have similar standard deviations to repeated measurements in the lab setting with healthy volunteer subjects. *Funding:* National Institutes of Health and National Science Foundation. (20 min.)

5-2 Wideband middle-ear muscle reflex test in a test battery to predict middle-ear dysfunction*

Douglas H. Keefe, Denis F. Fitzpatrick, Yi-Wen Liu, Chris A. Sanford, Michael P. Gorga

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ABSTRACT

Hypotheses: A wideband (WB) aural acoustical test battery of middle-ear status, including acoustic reflex thresholds (ARTs) and acoustic transfer functions (ATFs), is more accurate than 1-kHz tympanometry in classifying ears that pass or refer on a newborn hearing screening (NHS) protocol based on otoacoustic emissions. WB ARTs vary with subject age, reflex activator type, and hearing status. *Background:* Accurate assessment of middle-ear status would improve NHS programs inasmuch as many referrals from NHS programs are due to transient middle-ear dysfunction. *Methods:* Subjects included newborns recruited from a well-baby nursery (N=455 ears), children age 3-10 y., and adults. Ambient-pressure ATFs included energy absorbance and acoustic admittance. The ipsilateral reflex stimulus consisted of four broadband-noise (BBN) activator pulses alternating with five clicks presented before, between and after the activator pulses. Measurements were performed at 10 activator levels in 4-dB steps. The reflex shift was defined as the difference between final and initial click responses. Reflex shifts were quantified by objective, maximum-likelihood estimates of ART, separately calculated for low (ART-L from 0.8-2.8 kHz) and high (ART-H from 2.8-8 kHz) frequencies. ARTs were also measured using tonal activators. *Results:* ARTs were present in 98% of newborns passing the NHS, and in 87% at high frequencies up to 8 kHz. The mean ART-L was elevated by 14 dB in NHS refers compared to passes. An optimal combination of ATF and ART tests performed better than either test alone in predicting NHS outcomes, and either WB test performed better than 1-kHz tympanometry. WB ARTs measured in infants, children and adults showed developmental differences varying with reflex activator type, and were elevated in children with conductive hearing loss. *Conclusions:* Objective WB ART tests combined with ATF tests may improve the accuracy of screening protocols to identify hearing loss. *Funding Source:* NIDCD grants DC003784, DC006607, DC00013 & DC004662. (20 min.)

5-3 What does acoustic reflectance tell us about the middle-ear?

Patricia S. Jeng, Jont B. Allen, Harry Levitt

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ABSTRACT

The acoustic signal reflected off the eardrum is a frequency dependent complex signal conveying considerable information on middle-ear function. Information conveyed by this signal includes power reflectance, power absorption and transmittance as well as the complex impedance of the eardrum (resistance and reactance). Each of these variables provides useful information on middle-ear function in both normal and impaired ears. Each variable has both strengths and weaknesses, depending on the purpose of the measurements. Data on normal and impaired ears in infants, children, and adults will be interpreted in terms of these variables. Impairments to be considered include otosclerosis, eardrum perforation and otitis media with effusion. *Funding Source: NIH NIDCD. (12 min.)*

5-4 Umbo and stapes vibration measurements reveal middle-ear pathology in aged guinea pigs*

Diana Turcanu, Ernst Dalhoff, Andreas Heyd, Anthony W. Gummer

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ABSTRACT

Hearing loss in aged guinea pigs has been attributed in many studies to age-related inner-ear pathology. Nevertheless, two studies have shown that aged guinea pigs suffer from conductive hearing loss and that osteitic changes may be present in the middle ear of these animals. Using a laser Doppler vibrometer to measure the vibrations of the umbo and the stapes, together with evaluation of neural threshold using compound action potential (CAP) threshold tuning curves, we investigated the possibility of middle- and inner-pathologies in aged animals. Vibration measurements were performed on the umbo and the stapes of young (3 – 5 months) and aged (1 – 3 years) guinea pigs. The frequency responses of the umbo and stapes were measured in the frequency region 0.5 – 15 kHz, followed by measurement of distortion product otoacoustic emissions (DPOAEs) as vibration of these middle-ear structures. The parameters for the DPOAE measurements were: $f_2/f_1 = 1.2$ and $f_2 = 5 - 15$ kHz, $L_2 = 25 - 75$ dB SPL and $L_1 = 0.46L_2 + 41$ dB. Hearing thresholds were established from CAP recordings. Hearing loss, found in nine of the 11 aged animals, was accompanied by lower vibration amplitudes of the umbo (0 – 33 dB) and stapes (0 – 22 dB). The mechanical losses were more pronounced below 3 kHz, and the responses

showed a shift of the first resonance toward higher frequencies (1-2 oct). The slopes of the DPOAE input/output (I/O) functions proved to be less steep by a factor of about 3 than in the control animals, indicating middle-ear pathology. There was concomitant loss of CAP thresholds, such that the neural losses could be attributed to middle-ear pathology. Two of the animals showed normal neural and middle-ear vibration responses. These findings suggest fixation of the malleus-incus complex in 75% of the aged guinea pigs in our breeding colony. Therefore, aged guinea pigs might not be suitable as a model for studying age-related inner-ear changes. In conclusion, vibration measurements on the umbo and on the stapes in aged animals allowed evaluation of the middle-ear transfer function to quantify inner- and middle-ear losses separately. (12 min.)

5-5 Stroboscopic holography Measurement of motion of human tympanic membrane: a preliminary study*

Jeffrey Tao Cheng^{1,2}, Antti A. Aarnisalo^{1,2}, Ellery Harrington⁴,
Maria del Socorro Hernandez-Montes⁴, Cosme Furlong^{1,2,4},
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ABSTRACT

Sound-induced motion of the human tympanic membrane (TM) is studied by computer-assisted opto-electronic holographic interferometry acting in a stroboscopic mode that allows quantification of the displacement amplitude and phase of the entire surface of the TM. Measurements are made with tonal stimuli at 0.5, 1, 4 and 8 kHz. At 0.5 and 1 kHz, the entire TM surface moves roughly in-phase with some small phase delay apparent between local maximal displacement areas in the posterior half of the TM. At 4 and 8 kHz, the motion of the TM is more complicated, with multiple local maxima and minima arranged in rings around the manubrium. Generally, these local extrema move either nearly in-phase, or nearly out-of-phase. The patterns are consistent with a combination of low and higher order modal motions plus some small traveling-wave components. These observations of the dynamics of TM surface vibration will help us better understand the sound-receiving function of the TM and how it couples sound to the ossicular chain and inner ear. (20 min.)

6 ME HEARING AIDS I

Moderators: Daniel F. Wengen, Rong Z. Gan

6-1 The EarLens System: New Sound Transduction Methods*

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ABSTRACT

Hypothesis: The hypothesis that an open canal hearing device with a microphone in the ear canal can provide amplification over a wide-bandwidth is tested. *Background:* A thin silicone platform with an embedded transducer is placed on the tympanic membrane. The perception of sound is created when the “tympanic transducer” vibrates. A microphone placed in the ear canal senses the environmental sound including sound localization cues and addresses the most common problem experienced by the hearing impaired: understanding a target speaker in a multi-talker environment. *Methods:* Sixteen subjects (normal to moderate hearing impairment) wore the tympanic transducer for up to a six-month period were monitored for any adverse reactions. Three key functional characteristics were measured: maximum effective sound pressure level, feedback gain margin, and tympanic membrane damping. *Results:* Measurements indicate that the tympanic transducer remained in place and was well tolerated. With the tympanic transducer, the system had sufficient output to treat 60 dB of hearing impairment up to 8 kHz in 84% of the population and up to 11.2 kHz in 50% of the population. The feedback gain margin was on average 30 dB except at the ear canal resonance frequencies of 3 and 9 kHz where the average was reduced to 12 dB and 23 dB, respectively. The maximum tympanic membrane damping of 5-8 dB was in the 2-4 kHz range. The clinical data presented is for a magnetic implementation of the tympanic transducer. Other variations using different types of energy are discussed. *Conclusions:* The tympanic transducer and associated system has a wide effective bandwidth and little feedback, which opens up possibilities for a unique hearing system. The intra canal microphone configuration will provide the high frequency pinna diffraction cues (>6kHz) to facilitate better hearing in multi-talker environments. Work supported in part by NIDCD/NIH SBIR grants and approved by WIRB #20061405. (12 min.)

6-2 Performance Considerations of Prosthetic Actuators for Round-Window Stimulation*

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ABSTRACT

Round window (RW) stimulation has improved speech perception in patients with mixed hearing loss. In cadaveric temporal bones, Nakajima et al. (submitted to *Otology & Neurotology*, 2009) showed that RW stimulation with the FMT (MED-EL, Soundbridge) prosthesis produced differential pressure across the cochlear partition (a measure of the input to cochlear transduction) similar to normal forward sound stimulation above 1 kHz, when contact area between the prosthesis and RW is secured. However, there is large variability in the cochlear response within the temporal-bone sample, as well as in the hearing improvement in patients implanted with existing modified prosthesis. This is likely because the middle-ear prosthesis used for RW stimulation was designed for a very different application.

In this paper we utilize recently developed experimental techniques that allow for the calculation of performance specifications for a RW actuator. In cadaveric human temporal bones, we simultaneously measure scala vestibuli and scala tympani intracochlear pressures, as well as stapes velocity and ear-canal pressure, during normal forward sound stimulation as well as reverse RW stimulation. We then calculate specifications such as the impedance the actuator will need to oppose at the RW, the force with which it must push against the RW, and the velocity and distance by which it must move the RW to obtain cochlear stimulation equivalent to that of specific levels of ear canal pressure under normal sound stimulation. This information is essential for adapting existing prostheses and for designing new actuators specifically for RW stimulation. (12 min.)

6-3 Influence of FMT coupling parameters on vibration transmission to the round window*

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ABSTRACT

Background: With direct placement of a Floating Mass Transducer (FMT) at the round window niche, a new approach of coupling an implantable hearing system to the cochlea has been introduced successfully by Coletti in 2005. *Hypothesis:* Our study aims to define the best placement of the FMT at the round window regarding the resulting vibration transfer to the cochlear fluids. *Material and Methods:* Experiments were performed with laser Doppler vibrometry (LDV) on nine ears of six human anatomical whole head specimens. A facial recess approach was performed to gain access to the middle ear structures. The following setups of the FMT at the round window were examined: perpendicular and 90° turned, each with intact and disrupted ossicular chain, with tight fixation, underlayed and overlayed with connective tissue. The FMT was then stimulated electrically and the displacement of vibration of the FMT, the stapes head and the promontorial bone were measured using LDV. In one cadaver head the effect of a bone anchored hearing aid (BAHA), attached on a screw placed behind the auricle was compared to a FMT fixed to the promontory with cement. *Results:* Vibration transmission to the measuring point at the stapes was best with the FMT placed in the round window in a perpendicular way and underlayed with connective tissue. Tight fixation of the FMT to the round window showed significantly lower vibration transmission compared to all other types of placement investigated. Although measurable, bone conduction from the promontory fixed FMT was much lower than the effect of the BAHA. *Conclusions:* Our results suggest that the FMT does not act as a small bone anchored hearing aid. The coupling of the FMT to the round window has a substantial impact on the vibration transmission to the inner ear fluids. In our study, best results were obtained with the FMT placed in the round window and underlayed with tissue. *Funding Sources:* The Floating Mass Transducers used in this study were provided by Medel Inc, Innsbruck, Austria. Part of this study was supported by a Grant by the Swiss commission for Technology and Innovation (CTI 8075). (12 min.)

6-4 Experimental investigations on the coupling of an active middle ear implant on the round and oval window niche

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ABSTRACT

So far the coupling of active middle ear implants was thought for the intact and ventilated middle ear. Because of new technical developments middle ear implants like the vibrant soundbridge are also suitable in the case of disrupted ossicular chain and non aerated tympanic cavity. However, it is not known whether the coupling to the round window membrane or to the stapes provide better results in case of none ventilated middle ears. Five temporal bone specimens were perpetrated to simulate non ventilated middle ear cavities. The active middle ear implant vibrant soundbridge was used to contact either the oval or the round window niche. The actuator was directly stimulated with a multi-sinus of 50 mV amplitude. The resulting inner ear sound pressure was measured by a microphone at the round window or by Laser-Doppler-vibrometry at the stapes footplate. The influence of cartilage shield above the transducer, soft tissue and middle ear effusion were investigated in terms of differences in the frequency response function. In the results frequency dependent effects of the different coupling conditions are visible. Middle ear effusion attenuates the sound transmission by not more than 5 dB. In case of round window coupling worse transmission in the high frequency range was found more often than in case of stapes coupling. On the other hand lead round window coupling to more stable results in the low frequency region. The thickness of soft tissue and the contact area at the round window niche are also important factors. (12 min.)

6-5 The FMT positioning in the round window niche and its impact on hearing output in round window vibroplasty*

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ABSTRACT

Background: The round window application of the vibrant soundbridge, the so-called round window vibroplasty, is increasingly used in mixed hearing loss or total conductive block scenarios. The mechanisms of vibrocochlear stimulation and sonoinversion are unclear,

especially the importance of the FMT-round window membrane coupling and its impact on hearing outputs. We investigated the FMT positioning in relationship to the round window membrane (RWM) and the correlation to hearing outcomes. *Study:* Prospective cohort study with 20 Patients enrolled so far, investigating the round window application of the FMT for mixed hearing loss or total conductive hearing loss otherwise not aidable. *Methods:* Pre- and Postoperative hearing and speech scores as well as the aided postimplantation gains were assessed and correlated to the FMT position determined through a postimplantation high resolution temporal bone CT. *Results:* All patients attained normal speech intelligibility levels as well as a significantly improved SPIN when compared to conventional hearing aids. An inverse correlation between distance FMT- RWM to the hearing output was found. *Discussion:* Prerequisite for a successful hearing output was partial FMT contact to the RWM. Loss of contact resulted in complete loss of the vibrocochlear effects and hearing performance. A partial contact to the round window membrane is sufficient for a successful hearing performance. *Conclusion:* Our findings show that partial FMT-contact with the RWM is sufficient for successful hearing outputs in round window vibroplasty. Full contact of the FMT with the RWM seems not be required for effective coupling and hearing outputs. (12 min.)

6-6 Electrocochleographic and Mechanical Assessment of Round Window Stimulation with the Implantable Middle Ear Hearing Device*

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ABSTRACT

Background: Mechanical stimulation of the round window (RW) has shown some functional benefit in clinical reports. However, little objective physiological data on the efficacy of RW stimulation is available that can be used to guide candidate selection of mixed hearing loss patients. *Methods:* Cochlear microphonic (CM) and mechanical (stapes velocity) responses to sinusoidal stimuli were measured by electrode and laser Doppler vibrometry in response to normal acoustic stimulation via sealed calibrated insert earphone and to implant stimulation (Otologics MET-V, Boulder CO USA) of the RW without and with disarticulated middle ear chain in 8 chinchillas. *Results:* CM thresholds for acoustic stimulation were frequency dependent and ranged from 16-50 dB SPL. CM thresholds for RW stimulation ranged from -14 to 35 dB mV for intact middle ear chain and from -7 to 36 dB mV after disarticulation of the ossicular ear. Acoustically, stapes velocity showed maxima at ~700 Hz and minima at ~2.65 kHz. With application of the MET-V to the RW, stapes velocity showed a peak at 2-3 kHz. The equivalent sound pressure level (LE

max dB SPL) evoked with the RW stimulation With the MET-V was 60-105 dB for intact middle ear chain and 70-100 dB after disarticulation of the ossicular chain. Conclusion: Aside from threshold differences, driving the RW with the MET-V transducer produces evoked responses (CM) that were comparable to normal acoustic input. When adjusted for threshold, the sensitivity of the CM (slope) was virtually identical between the acoustic and MET-V stimulation of the RW. Mechanical stimulation of the RW with the MET-V can produce cochlear responses (CMs) and stapes velocities that are functionally equivalent to acoustic stimulation. (12 min.)

6-7 Optimization of round window drive with the MET-V transducer with different interposed collagen materials

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ABSTRACT

Background: While temporalis fascia (TF) has improved the coupling of electromechanical devices to the RW, we wished to test whether other collagen graft materials might further optimize the angled approach of the MET-V. **Methods:** Six fresh cadaver temporal bones were prepared with an atticotomy and extended transfacial recess approach to the RW. METRW drive was achieved via the inferior facial recess (~30° RW angle) or transjugular (90° RW angle) with a 1mm ball. Calibrated sinusoidal stimuli (0.25-14kHz) drove either a TDTCF speaker, via foam insert (80-100dBSPL), or the MET (1VRMSMax). A B&K microphone recorded TM surface sound pressures. Stapes, RW, and ball velocities were recorded by LDV. RW loading was assessed by graded deflection and calibrated micro-adjustment. The effect of interposed collagen materials on METRW drive efficiency was assessed by stapes velocity (HEV) and calculated peak equivalent sound pressures (LEmax). Four grafts were prepared as 2mm discs: human temporalis fascia (thin), fibro-fatty fascia (thick), Permacol® (xenograft) and Tutoplast® (allograft). Two further materials, cartilage and soft silastic, were used for comparison. **Results:** Five temporal bones had 'normal' stapes transfer functions (HTV) and cochlear hydration (normal HTV-RW~1mm/s/Pa, RW-stapes phase-lag~0.5cycle). For facial recess METRW drive the four collagen materials significantly improved stapes velocity by an average of 3.6dB (P<0.05). Tutoplast® performed significantly better than temporalis fascia (+7.5dB vs +3.8dB, p=0.003). Fibro-fatty fascia performed better than Permacol® (+2.2dB vs -0.31dB) both performing better in the 1-6kHz range (+5.4 & +1.8dB respectively). Cartilage and soft silastic impaired transmission (-9dB and -8dB). Smaller effects were seen for perpendicular drive (p>0.05). Without fascia the calculated mean LEmax for METRW drive at 1VRMS was 106 dBSPL for facial recess and

108 dB SPL for transjugular approaches ($p > 0.05$). The estimated mean LE_{max} achievable via the facial recess with the best fascia material is 113 dB SPL - comparing favorably with the mean LE_{max} for METincus drive of 126 dB SPL at 1VRMS. *Conclusions:* Tutoplast® achieved significantly improved mechanical drive to the cochlear and warrants further clinical investigation. *Funding Source:* Otologics Education Grant. (12 min.)

7 COMPUTATIONAL MODELS

Moderators: Elizabeth S. Olson, Margaret G. Wismer

7-1 On the mechanics of dehiscence in the superior semicircular canal

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ABSTRACT

Background: Depending on cranial volume and pressure a dehiscence in the upper semicircular canal shows different effects on the mechanical behavior of the middle ear and the corresponding hearing loss. *Hypothesis:* The objective of this study is to describe the effects of a dehiscence on the dynamical behavior of the ossicular chain in the middle ear as the input to the fluid system. Derived from the measurements on temporal bones appropriate mechanical models were established to interpret the results and to give an insight into the interrelationship of cause and effect. *Materials and Methods:* Several temporal bones were prepared to drill holes of different size into the upper semicircular canal. Fluid columns of different volumes and different pressures were connected to the temporal bones representing the situation in the cranial compartment. As input to the inner ear, the spatial motions of the stapes were measured using a 3D Laser Vibrometer. The motion of the round window was measured by means of a scanning LDV. For the interpretation of the measurement results simulations have been carried out based on a mechanical model. *Results:* The model allowed a description of the effects of dehiscence. Sensitivities of the middle ear dynamics on the size and location of the hole as well as the mass and pressure of the cranial fluid were derived. *Conclusions:* Mechanical models and simulations can be used for the investigation of potential mechanisms of a dehiscence. Their impacts on the spatial motions of the stapes as well as the related motions of the round window were demonstrated. (12 min.)

7-2 Evaluation of implantable actuators by means of a middle ear simulation model

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ABSTRACT

The extension of indication of implantable hearing aids to cases of conductive hearing loss pushed the development of these devices. There is now a great variety of devices with different actuator concepts and different coupling to the middle ear (or inner ear). But there is little comparative data available about the devices. The present study is aimed to provide data about different actuator concepts. Microphone, amplifier and signal processing electronics and mechanisms of feedback cancellation were not incorporated. Investigations were performed by means of a mathematical simulation model of the middle ear (Finite Element Model). The following actuator principles were studied: conventional hearing aid transducer, electrodynamic and piezoelectric actuator. The excitation of the middle ear by the actuator (displacement, force or sound pressure) was measured or estimated from technical data. The displacement of the stapes footplate was calculated as a measure for the energy transferred to the inner ear fluid. We compared this frequency transfer function at the stapes footplate (frequency range 100-6000 Hz) of the different actuators at different coupling positions and actuator directions. We also estimated the sound radiation through the ear canal in case of intact or reconstructed middle ears. This provides information about maximum possible actuator input (feedback) beside technical limitations due to the actuator concept. Results show that high stimulation amplitudes at low frequencies are hard to achieve with most actuator concepts. There is a wider influence of coupling position and actuator direction at low frequencies than at high frequencies. (12 min.)

7-3 Wave model of the human tympanic membrane*

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ABSTRACT

Understanding sound propagation in the ear is a key to a better diagnosis and treatment of hearing pathologies. Middle ear models have been developed for many years and have shed significant light on the behavior of the ear system. Most of those models are implemented in the frequency domain, where indeed the physical and mechanical equations are more easily derived. This is problematic, however, when it comes to model non-

linear phenomena, especially like those occurring in the cochlea. This research presents a different approach, based on a time-domain implementation. Volume velocity samples are distributed uniformly in space along the propagation path (ear canal, eardrum, middle ear) and updated periodically to simulate the propagation of the sound wave. This human model is adapted from a previously published model for the cat (Parent and Allen, Wave Model of the Cat Tympanic Membrane, JASA, August 2007). The model's results are in agreement with experimental reflectance measurements for normal and pathological ears, which demonstrates the validity of this time-domain approach to model the middle ear. This work is funded by Mimosa Acoustics, Inc. (Champaign, IL). (12 min.)

7-4 Towards high-realism physics based models of middle ear mechanics: high definition morphology, precise materials parameters and introduction of non-linearity

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ABSTRACT

Physics based models of the middle ear have become an invaluable tool for basic research of the auditory system and for the optimisation of ossicle prosthesis and middle ear implants. Accurate input data are essential to obtain correct results from model based calculations. While just a decade ago models made use of crude shape data, current models import geometry meshes obtained from actual measurements. Some experimental data on eardrum elasticity are available, and first attempts have been made to add the strongly non-linear ossicle motions in the quasi-static pressure range. In this paper we discuss ongoing research which is aimed at moving ME modelling into even more realism. Using a combination of ultra-high resolution X-ray tomography and optical virtual sectioning, we are working towards a high-definition morphological model of the middle ear ossicles and soft tissue structures. Tendons, joints and muscles are imaged using the optical technique, and their 3D models are added into a high resolution model of the ossicles and ME cavity. A complete surface mesh of the gerbil ME will be put to the disposal of the research community. Using a combination of moiré topography and micro-indentation we are determining eardrum elasticity parameters measured in-situ. Up till now, elasticity was mainly estimated from tension experiments, which use strains far outside of the physiologic relevant range. Using micro-indentation combined with finite element parameter optimisation, we are also determining the elasticity parameters of the ossicles, so general estimates can be replaced by precise values. Finally, we are measuring the non-linearities of the ME transfer function in the acoustic range, in an attempt to furnish experimental data to extend modelling into

the high sound pressure range. In this presentation, an outline of the techniques and their results is given. Details on methods and results are discussed in dedicated presentations. (20 min.)

7-5 Finite-element modelling of the configuration changes of the ossicular chain with static pressure

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ABSTRACT

Background and Hypothesis: Recently we have measured the change in ossicular configuration with large ambient pressures using micro-computed tomography in combination with a warping analysis (S. Gea et al., MEMRO 2006). Three-dimensional displacement and deformation were obtained for the entire ossicular chain in human and gerbil. To understand the underlying mechanics a finite-element study is being undertaken and the early stages of this venture are presented. *Materials and Methods:* For the present study non-linear large-displacement simulations must be carried out, in contrast to the linear models used for middle-ear vibrations. Some features of the middle ear that were of lesser importance for the vibrational models are now of utmost importance. For example, the contact areas, interstitial spaces and joint capsules of the ossicular joints must be represented. The shapes of the stapes footplate and oval window must be precisely defined. The ligaments and muscles must be correctly represented. And the tympanic membrane must be modelled with its natural shape and correct elastic characteristics. CT scans and histological serial sections along with specialized software were used to define the models. *Results:* We will discuss some of the issues touched upon above and present the current state of our models, which are made for each individual experimental ear. This lets us also discuss inter-individual differences. *Conclusions:* This project is ambitious, but we have already dealt with some of the many sub-problems in previous papers (TM deformation, incudostapedial joint, finite-element model making based on CT) so we expect to be able to show in the near future that finite-element modelling is applicable to describe ossicular-chain deformation with static loads. *Funding Sources:* Research Fund of Flanders (Belgium), Canadian Institutes of Health Research and Natural Sciences and Engineering Research Council (Canada). (20 min.)

7-6 Nonlinear Stiffness Characteristics of the Ossicular Chain

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ABSTRACT

Hypothesis: Linear middle ear models are not sufficient to describe middle ear kinematics and dynamics in case of preloaded ossicular chains as for example in reconstructed ears or high static pressures. These situations may appropriately described by nonlinear middle ear models. *Background:* Most passive prostheses and active implants need a sufficient preload to assure permanent coupling to ossicles, tympanic membrane or skull. Due to nonlinear properties of the middle ear the imposed preload is expected to change the transfer characteristics significantly. High static pressure has a similar effect on the ossicular chain and occurs for example in diseased ears with malfunction of the eustachian tube or inflammation of the middle ear as well as in normal ears during tympanometry. *Materials and Methods:* Temporal bones from human cadavers were used. Using a laser vibrometer the spatial displacement of the stapes footplate was picked up in regard to different static pressures in the ear canal as well as specific forces of a load cell on several points on the stapes footplate. Out of the static pressures and forces, respectively, and the spatial displacements of the stapes footplate, nonlinear stiffness properties of the ossicular chain were derived. *Results:* The middle ear behaves highly nonlinear at static preloads. Out of the measurements parameters of a nonlinear mechanical middle ear model were determined. *Conclusions:* The nonlinear properties of the ossicular chain plays an essential role particularly with regard to the preload inserted while coupling passive or active implants with the ossicles. Nonlinear models enable the description of the discussed effects and allow deriving important advices for the clinical practice. *Funding Source:* DFG (German Research Council) (12 min.)

7-7 Measuring the quasi-static Young's modulus of the eardrum using indentation technique*

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ABSTRACT

Background: Accurate estimation of the quasi-static Young's modulus of the eardrum is important for finite-element modeling of clinical procedures such as tympanometry. However, there is substantial variability in estimated values of the Young's moduli reported in the literature, even for the same species. Although intra-specimen variations may account for a portion of the variability, differences in experimental protocol and in simplifying assumptions used in the calculations can also give rise to the large differences in values reported by various authors. *Objective:* In this study, we adapt a tissue indentation technique and inverse finite-element analysis to estimate the Young's modulus of the eardrum. *Method and Materials:* A custom-built indentation apparatus was used to perform indentation testing on 7 rat eardrums ex vivo after immobilizing the malleus to avoid the confounding effects of the ossicular chain and cochlear load on eardrum response. Testing was done on the posterior pars tensa. The unloaded shape of each eardrum was measured using a Fourier transform profilometer, a non-contacting optical technique. Finite-element models were constructed for each eardrum from corresponding shape measurements in order to simulate the indentation procedure. The Young's modulus of each specimen was then estimated by numerically optimizing the Young's modulus of each model so that simulation results matched corresponding experimental data for that specimen; the Fibonacci optimization algorithm was used. *Result:* Assuming a thickness value of 12 microns for the thickness of each model eardrum, the estimated Young's modulus was found to be 21.7 MPa \pm 1.2 MPa. *Conclusion:* The estimated average Young's modulus is within the range reported in the literature, lending confidence to the technique. Moreover the low variability in the measurements for healthy specimens suggests that the technique is highly repeatable. (12 min.)

7-8 Quantification of tympanic membrane elasticity parameters from in situ measurements*

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ABSTRACT

Correct quantitative parameters to describe tympanic membrane elasticity are an important input for realistic modeling of middle ear mechanics. In the past, several attempts have been made to determine tympanic membrane elasticity from tensile experiments on cut-out strips. The strains and stresses in such experiments may be far out of the physiologically relevant range and the elasticity parameters are only partially determined. We developed a setup to determine tympanic membrane elasticity in situ, using a combination of point micro indentation and Moire profilometry. The measuring method was tested on latex phantom models of the tympanic membrane, and our results show that the correct parameters can be determined. These parameters were calculated by finite element simulation of the indentation experiment and parameter optimization routines. As latex is a strongly nonlinear material, a hyperelastic constitutive model was used. When the apparatus was used for rabbit tympanic membranes, Moire profilometry showed that there is no measurable motion of the manubrium during the small indentations. This result greatly simplifies boundary conditions, as we may regard both the annulus and the manubrium as fixed without having to rely on fixation interventions. The technique allows us to determine linear elastic material parameters of a tympanic membrane in situ. In this way our method takes into account the complex geometry of the membrane, and parameters are obtained in a physiologically relevant range of strain. (12 min.)

7-9 Middle-ear "gear" adaptation for high-frequency transmission*

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ABSTRACT

Hypothesis: Contrary to the predictions of classical models, middle-ear sound transmission is not limited by ossicular mass at high frequencies. We hypothesize that this is because of a low-inertia "twisting" mode of the malleus that, combined with the properties of the mobile saddle-shaped malleus-incus joint, allows for efficient sound transmission to the cochlea at high frequencies. *Background:* The unique capacity for high-frequency hearing in mammals is thought to have evolved as a means of localizing sound (Masterson et al., 1969). Several specific adaptations are thought to contribute to this capacity, including the presence of three distinct middle-ear bones. *Materials and Methods:* Micro-CT-based 3-D volume and surface reconstructions of the malleus, incus, and eardrum were obtained for human, cat, chinchilla, and guinea pig temporal bones. Ossicular moments of inertia

and eardrum surface areas were calculated based on the reconstructions for each species. *Results:* For both human and cat, the moment of inertia of the malleus is more than five times smaller for rotational motions about the long axis (inferior-superior), than for rotations about the other two orthogonal axes. For both guinea pig and chinchilla, however, the minimum corresponds to rotations through the short axis (anterior-posterior) of the fused malleus-incus complex. Additionally, the eardrum surface is asymmetrically divided by the malleus handle for human and cat, but not for guinea pig and chinchilla. *Conclusions:* In human and cat, whose ossicles are more massive than those of chinchilla and gerbil, the classically-predicted limitations of mass inertia at high frequencies may be offset, with the help of eardrum asymmetry, by a switch to a “twisting” motion of the malleus. Because the malleus-incus joint in human and cat is saddle-shaped and flexible, it may be capable of transforming this motion into appropriate incus motion, much in the way a helical or bevel gear would operate. *Funding Source:* Work supported by grant No. DC05960 from the NIDCD of NIH. (12 min.)

8 IMAGING TECHNOLOGIES

Moderators: Alexander M. Huber, Michael L. Gaihede

8-1 Rotational Tomography as a tool for quality control in reconstructive middle ear surgery (an experimental and clinical study)

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ABSTRACT

Hypothesis: Evaluation of RT as a new imaging tool for immediate quality control following middle ear surgery. Determination of RT's possible predictive value on functional outcome by estimation of prostheses position and -angles. *Background:* Remaining air-bone-gaps (ABG) may allow speculation about failure in the otosurgeon's reconstructive procedure. In contrast to invasive procedures like second-look-surgery new imaging techniques (e.g. Rotational Tomography/RT) open new possibilities for quality control in reconstructive middle ear surgery. RT offers depiction of middle ear anatomy in comparable quality to Computed Tomography (CT) but comparably lower irradiation exposure and almost artifact-free visualization of metallic mid. *Materials/Patients and Methods:* Performance of

experimental investigations in 29 temporal bone specimen: simulated middle ear surgery including titanium middle ear implant insertion (TORP, PORP) in all specimen. Use of Laser-Doppler- Vibrometry (LDV) for definition of pre-/ post-operative middle ear transfer function and investigation using RT. 87 patients who had undergone reconstructive middle ear surgery were included in a clinical study. All patients underwent postoperative audiometric controls and RT-examination. *Results:* A 3-dimensional-view of the temporal bone anatomy, localization of prostheses within the reconstructed middle ear as well as angle determination of inserted prostheses towards the tympanic membrane and/or the malleus handle were achieved by means of RT. Reconstructive surgical steps (e.g. prosthesis coupling) could be clearly visualized. Implant position was correlated either with LDV- measurement of middle ear transfer function in temporal bones or with audiometric controls in patients. *Conclusions:* Concluding from clinical and experimental results of our study RT seems to be a valuable and promising tool for immediate postoperative quality control after reconstructive middle ear surgery. *Funding Source:* This study was financed with support from the ORL- Depts. of Freiburg and Dresden/ Germany. (20 min.)

8-2 Reconstruction and Exploration of Virtual Middle Ear Models Derived from Micro-CT Datasets*

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ABSTRACT

Background: Middle ear anatomy is integrally linked to both its normal function and its response to disease processes. MicroCT imaging provides an opportunity to capture high-resolution anatomic data in a relatively quick and non-destructive manner. However, to optimally extract functionally relevant details, an intuitive means of reconstructing and interacting with this data is needed. *Materials and Methods:* A microCT scanner vivaCT 40 (<http://www.scanco.ch>) was used to obtain high-resolution scans (10 microns in plane, 16 microns out of plane) of fresh explanted human temporal bones. We adapted a previously developed Stanford Virtual Surgical Environment (VSE), to enable real-time reconstruction, display, and manipulation of these volumetric datasets. Custom designed software provided for semi-automated threshold segmentation. A 6-degree-of-freedom navigation device was designed and fabricated to enable exploration of the 3D space in a manner intuitive to those comfortable with the use of a surgical microscope. Standard haptic devices (Sensable Technologies, Woburn, MA) were also incorporated to assist in

navigation and exploration. *Results:* Our VSE could be adapted to allow for the effective exploration of middle ear microCT datasets. Functionally significant anatomic details could be recognized and objective data extracted. *Conclusions:* We have developed an intuitive, rapid, and effective means of exploring otologic microCT datasets. This system may provide a foundation for additional work based on middle ear anatomic data. *Funding Source:* NIDCD of NIH grant DC05960. (12 min.)

8-3 Mastoid structural properties determined by imaging analysis of high resolution CT-scanning*

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Affiliation: 1) Department of Otolaryngology, Head and Neck Surgery, Aalborg Hospital, Aarhus University Hospital, Denmark; 2) Department of Biomedical Engineering, and 3) Center for Medical Image Science and Visualization, Linköping University, Sweden

ABSTRACT

Hypothesis: The structure of the mastoid air cells can be described by quantitative imaging analysis of high-resolution CT-scans, which may contribute to understand its function in normal and pathological ears. *Background:* Negative middle ear pressure is a common factor in middle ear diseases resulting from an imbalance between mastoid gas exchange and Eustachian tube function. While the Eustachian tube function has been the main focus of research, more recent studies indicate that the mastoid may play an active role in pressure regulation. The mastoid structure with numerous air cells reflects a large area to volume ratio (AV-ratio) adapted to efficient gas exchange. Imaging analysis applied to high resolution CT-scanning can describe quantitative measures, which may reveal important information about mastoid function and its role in healthy and diseased ears. *Materials and Methods:* Quantitative analysis was performed on a series of unselected high resolution CT-scans (voxel size: 0.29*0.29*0.625 mm) from 36 ears in 24 patients. Area and volume were determined using Cavalieri's method, i.e. by summing cross-sectional areas. The AV-ratio was computed for each scan. *Results:* Mean area was 69 cm² (range: 23-134), mean volume was 4 cm³ (range: 1.3-10.8 cm³), and mean AV-ratio was 16 cm⁻¹ (range: 11.2-21.0 cm⁻¹). The area correlated linearly to the volume by $A=17.2*V-0.2$. *Conclusion:* The area and volume values corresponded with previous studies, and the additional AV-ratio reflected the functional properties of the mastoid in terms of capability for gas exchange. Due to a series of similarities between structure and function of the lungs and mastoid, it seems likely to propose a tree-structure of dividing mastoid cells. In respiratory research, analysis describing the dimensions of series of bronchi generations has been applied, and based on current results, our aim of future research is to establish similar details of mastoid tree-structure. *Funding Source:* Various private Danish funds. (12 min.)

8-4 In house developed navigated mechatronic system for implantable hearing devices*

Christof Stieger¹, Marco Caversaccio², Andreas Arnold², Guoyan Zheng¹, Jonas Salzmann¹, Yves Mussard³, Martin Kompis², Rudolf Häusler², Stefan Weber¹

Affiliation: 1) ARTORG Center, University Bern, Switzerland; 2) University Department of ENT, Head and Neck surgery, Inselspital, Bern, Switzerland; 3) Laboratory for Microrobotic, University of applied Science Bern, Switzerland

ABSTRACT

For cochlea implants and other implantable hearing devices, a transmastoid approach to the tympanic cavity as well as the formation of a bone bed for the electronics are necessary. A navigation-controlled mechatronic device could support the surgeon, especially with a minimally invasive transmastoid approach to the tympanic cavity. A miniaturized in-house designed robotic system five degrees of freedom with an integrated drill so called AIMAN is presented. Laboratory tests have been performed. First the workspace of the robot was evaluated. The working range (superior-inferior 100mm, anterior-posterior 55mm, proximal-distal 65mm) is considerably greater than the dimensions measured on a synthetic petrous bone during conventional mastoidectomy (superior-inferior 22.5mm, anterior-posterior 19.5mm, proximal-distal 27.5mm). The workspace is also sufficient to perform drilling beds for known implant electronics. In the second test the accuracy of the robot was evaluated. A rotational accuracy of $0.6 \pm 0.6^\circ$ and a translational accuracy of 1.4 ± 0.5 mm were found which is in the order of other known systems such as the PathFinder and NeuroMate. (12 min.)

8-5 Multiphoton and Electron Microscopy of Collagen in Ex Vivo, Human Tympanic Membranes

Ryan P. Jackson^{1,2,3}, Tony Ricci², Cara Chlebicki⁴, Tatiana B. Krasieva⁴, Reena Zalpuri⁵, William J. Triffo⁵, Sunil Puria^{1,2,3}

Affiliation: Stanford University, 1) Departments of Mechanical Engineering, 2) Otolaryngology-HNS, and 3) Palo Alto Veterans Affairs; 4) UC Irvine, Beckman Laser Institute; 5) UC Berkeley, Electron Microscope Lab

ABSTRACT

Hypothesis: The eardrum contains anatomical features important to the biomechanical mechanism that enables high-frequency hearing for terrestrial mammals. These features can be effectively studied by multiphoton and electron microscopy. *Background:* We are investigating the role of middle-ear biomechanics in high-frequency hearing for several terrestrial mammals. In particular, the upper frequency hearing limit (UFHL) for humans is about 20 kHz. The ability to hear these high frequencies may be partially due to the

anatomy of the composite structure of the eardrum, which consists of highly structured collagen layers surrounded by soft tissue, and the connection of the eardrum to surrounding structures. *Materials and Methods:* We have imaged ex vivo human eardrums (one day post mortem) by multiphoton microscopy (MPM; n = 13); transmission electron microscopy (TEM; n = 3); and scanning electron microscopy (SEM; n = 5). The excitation wavelength for MPM imaging was 920 nm, which enabled the collection of both two-photon fluorescence (TPF), isolated at 535-590 nm, and second harmonic generation (SHG), isolated at 435-485 nm, light for imaging. SHG generates stronger signal from collagen molecules, so imaging of the collagen layers versus the other biological material was possible. TEM and SEM imaging were carried out according to conventional protocols using glutaraldehyde fixed samples. *Results:* Collagen fibrils and fibers were clearly visible in our images and appeared to conform to the images in the literature. *Conclusions:* We have obtained preliminary images of collagen structure in the human eardrum using multiphoton microscopy and electron microscopy. We will continue imaging and developing three-dimensional maps of collagen fiber micro- and ultra-structure in the eardrum. In the future, we will expand our study to include other terrestrial mammals commonly studied in hearing science. *Funding Source:* Work supported in part by the National Institutes of Health Grants: T32 MSTP (Jackson), LAMMP P41 RR01192 (Krasieva), and R01 DC05960 (Puria). (12 min.)

9 PASSIVE PROSTHESES II

Moderators: Andreas Arnold, Irina Arechvo

9-1 Extracellular bone matrix components on titanium prostheses induce osseointegration on the stapes footplate

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ABSTRACT

Background: Save and stable coupling between prostheses and the ossicular remnants is crucial for good postoperative hearing results after ossiculoplasty. To establish a stable fixed-point on the stapes footplate for subsequent prosthesis reconstruction, a titanium footplate anchor was coated with components of the extracellular bone matrix to induce a controlled osseointegration on the footplate. *Materials and Methods:* Specially designed titanium footplate anchors were implanted on the stapes footplate of one-year-old Merino

sheep. The implants' surfaces were modified by applying a collagenous matrix with bone morphogenic protein (BMP-4) and transforming growth factor- β (TGF- β) to stimulate osteoblastic differentiation and activation on the stapes footplate with subsequent osseointegration. Brainstem evoked response audiometry was used to observe hearing and polychrome labeling was used to assess new bone formation and remodeling during the study. After study termination on day 84 synchrotron radiation based computed microtomography and histomorphometry were used to identify bone implant contact. **Results:** During the study bone conduction thresholds remained stable in all groups. Histologically, an osseointegration of the implanted prostheses was observed in two surface coated specimens. There was radiographical evidence for another 8 implants to be integrated into newly formed bone. A footplate fixation in the oval niche by an excessive bone formation was never observed. **Conclusions:** These results prove the general ability to induce a controlled osseointegration of titanium implants on the stapes footplate in a mammalian organism. Once a bone fixed anchor is established on the footplate further individual prosthetic assemblies could improve middle ear reconstruction. (12 min.)

9-2 Microstructuring and bioactive nanolayer coating of titanium surfaces for middle ear ossicular replacement prosthesis*

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ABSTRACT

Introduction: While a variety of materials have been evaluated for replacement of human middle ear ossicles following inflammation, titanium and its alloys have shown excellent sound transmission properties and biocompatibility. However, cartilage thickness at the tympanic membrane interface deteriorates over time, while fibrous tissue formation may dislodge the titanium prosthesis. This study was performed to evaluate the effect of microstructures and bioactive nanolayer coating on titanium surfaces in contact with adjacent biological tissue. **Materials and Methods:** Titanium samples of 5mm diameter and 0,25mm thickness were structured by means of a Ti:Sapphire femtosecond laser operating at 970nm. The structures applied were lines of parabolic shape (cross-sectional) of 5 μ m (parallel), 5 μ m (cross-hatch) and 10 μ m width (parallel). The inter-groove distance between two maxima was exactly twice the line width. In addition, PVDF foil samples were covered with a hydrogel layer in conjunction with RGD peptide sequence which provided a linker for bone matrix protein (BMP-7) molecules. **Results:** Lines smaller than 5 μ m were not feasible due to the natural irregularity of the basic material with pits and level changes of up to 2 μ m. The process showed little debris and constant microstructure shape over the whole structured area (2x2mm). The resulting debris was examined for

toxic by-products on human fibrocytes and chondrocytes. Bioactive nanolayer coating displayed no cytotoxic properties for chondrocyte cell growth, although the impact of surface-bound BMP-7 in contrast to soluble BMP-7 on cell growth is still subject to evaluation. *Conclusion:* The results show that microstructures can be applied on titanium surfaces for human implantation with reproducible and constant shapes. Further studies will focus on cell culture of uncoated titanium surfaces which has suggested a relative selectivity for chondrocyte compared to fibrocyte growth in earlier studies, versus bioactive nanolayer coated surfaces. *Funding Source:* This study is being funded by the “Deutsche Forschungsgemeinschaft” (German Research Foundation), Transregio 37 (Aachen-Hannover-Rostock), Project B3. (20 min.)

9-3 Prosthetic Reconstruction to the Stapes Head or to the Stapes Footplate? A Laser Doppler Study

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ABSTRACT

Background: It is generally accepted that with a missing incus, reconstruction to the stapes head is more effective than reconstruction to the stapes footplate. However, this has rarely been tested empirically. Better results reported with reconstruction to the stapes head might simply reflect less underlying disease in these ears. *Objectives:* To compare vibration transmission of prosthetic Tympanic membrane Assembly to Stapes Head (TASH) reconstruction with Tympanic membrane Assembly to Footplate (TAF) reconstruction in a fresh human temporal bone model. What is not clear is if there is a mechanical penalty to be paid for with reconstructing to the stapes footplate instead of the superstructure. Our research question was whether the mechanics of reconstruction to the stapes head was in some way, per se, more efficient than reconstruction to the stapes footplate, per se. *Methods:* After incus removal, the discontinuity was repaired using a titanium prosthesis from the eardrum to the stapes head or to the stapes footplate. Pure tone sound sweeps were presented and round window (RW) vibrations were measured with a laser Doppler vibrometer. *Results:* Reconstruction of both types decreased RW vibrations by 10-15 dB

between 500-3000 Hz compared to the intact ear. There was a tendency for reconstruction to the stapes head (TASH) to perform better at lower frequencies, but this was only statistically significant at 1 and 2 kHz. *Conclusions:* There may be a small mechanical advantage in reconstruction to the stapes head for frequencies below 2 kHz. (12 min.)

9-4 Tight Stapes Prosthesis Fixation Leads to Better Functional Results in Otosclerosis Surgery

Alexander M. Huber¹, Jae Hoon Sim¹, Roman Laske¹, Dorothe Veraguth¹, Stephan Schmid², Thomas Roth³, Albrecht Eiber⁴

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ABSTRACT

Background: The optimal prosthesis to use for otosclerosis surgery is still a matter of debate. It has been proposed that using self crimping prostheses made of Nitinol, a shape-memory metal, produces better functional results with less variability and reduced risk for middle and inner ear damage. This is thought to be because heat activation rather than manual crimping of the prosthesis loop forms a tighter fixation. *Hypothesis:* Tight fixation of stapes prostheses yields better functional results because sound transmission from the incus to the prosthesis is improved. *Methods:* Functional results of two clinical groups with self crimping and conventional prostheses containing 150 patients were compared one year post surgery. Crimping quality was measured by intraoperative Laser Doppler interferometry (LDI). Causality was assessed by correlating results of intraoperative LDI and postoperative pure-tone thresholds. Assessment during revision surgery allowed evaluation of the acoustic effect of ingrown tissue between the incus and the stapes prosthesis. *Results:* Sound transmission was improved by 2.5 dB with the self crimping prostheses as compared to conventional prostheses when measured intraoperatively by LDI. These differences were statistically significant. Intraoperative fixation quality was positively correlated to functional outcome. Ingrown tissue between incus and prosthesis has only small effects on sound transmission. *Conclusion:* Tight fixation, as provided by self crimping prostheses leads to improved functional results because of better sound transmission properties at the incus- prosthesis interface. Nitinol prostheses provide an effective treatment option in otosclerosis surgery. The known limitations of the currently available Nitinol prostheses lead to the development of an optimized prosthesis system. *Funding:* University Zurich. (20 min.)

9-5 Malleovestibulopexy using titanium MVP clip piston

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110 095 INDIA

ABSTRACT

Background: After introduction of stapes surgery, malleovestibulopexy (MVP) was the logical extension of this procedure. Although the hearing results of stapes surgery were usually 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. *Objectives:* To evaluate the hearing outcomes of malleovestibulopexy using titanium MVP clip piston which has recently been introduced. *Methods and Material:* Eight patients undergoing exploratory tympanotomy for congenital conductive 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 piston insertion depth in the vestibule. Drilling of malleus handle with diamond burr for making a groove was required in five 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 eight cases and within 10 dB in six cases. No deterioration of bone conduction threshold was observed. *Conclusions:* The hearing results of malleovestibulopexy using newly introduced titanium MVP clip piston 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. (12 min.)

10 PANEL DISCUSSION

Moderators: Alexander M. Huber, Albrecht Eiber

Panel Members: John J. Rosowski
Rodney Perkins
Samuel N. Merchant
Robert K. Jackler
Karl-Bernd Hüttenbrink
Kiyofumi Gyo
Rong Z. Gan
Nikolas H. Blevins

Please post your panel discussion questions on the Discussion Site *prior* to this session: <http://memro2009.stanford.edu/discussion/>.

11 BONE CONDUCTION & HIGH NOISE

Moderators: Albrecht Eiber, Douglas H. Keefe

11-1 Effect of the stapedius reflex on air conduction and bone conduction transmission in the human

Stefan Stenfelt

Affiliation: Dept of Clinical and Experimental Medicine, Linköping University, Linköping, Sweden

ABSTRACT

Hypothesis: Contraction of the stapedius muscle affects sound transmission by air conduction and bone conduction differently. *Background:* A contraction of the stapedius muscle decreases the sound transmission through the middle ear in the order of 10 dB for frequencies below approximately 1.5 kHz. It is not very clear how a stapedius muscle contraction affect sound transmission to the inner ear by bone conduction, but it is generally assumed that it affect the sound transmission by bone conduction less than it does by air conduction. *Materials and Methods:* Growth functions of Auditory Steady State Responses (ASSR) in the frequency range 0.5 to 4 kHz was measured in ten subjects. The ASSR stimuli were either supplied by air conduction or bone conduction. Simultaneously, a noise stimuli designed not to interfere with the ASSR stimuli was presented to elicit the stapedius reflex. By comparing ASSR growth functions at different eliciting levels, the influence from the stapedius reflex could be estimated. *Results:* It was found that the stapedius reflex decreases sound transmission by air conduction by 5 to 20 dB at frequencies

below 2 kHz and 0 to 5 dB when the stimulation is by bone conduction. *Conclusions:* The stapedius reflex attenuate air conducted sound at low frequencies more than it does bone conducted sound. (12 min.)

11-2 Experimental Validation of a Computational Model of Bone-Conducted Sound Transmission

Odile H. Clavier¹, Jesse A. Norris¹, Jed C. Wilbur¹, Ken J. Cragin¹, Anthony J. Dietz¹, Margaret G. Wismer², William D. O'Brien²

Affiliation: 1) Creare Inc., 16 Great Hollow Road, P.O. Box 71, Hanover, NH 03755; 2) Bioacoustics Research Laboratory, University of Illinois at Urbana-Champaign

ABSTRACT

Hypothesis: That the transmission paths of air and bone conducted sound around, into and through a human head can be accurately predicted by a three-dimensional acoustic wave propagation computational model. *Background.* Bone-conducted sound is the limiting factor in current hearing protection designs for very high noise environments such as those encountered by maintainers of military aircraft. The University of Illinois had developed a three-dimensional acoustic wave propagation model for the computation of sound transmission into, around, and through fluid, solid, and solid-shell bodies. The aim of this modeling effort is to provide a capability for analyzing and improving hearing protection designs. Creare has implemented experimental techniques to obtain validation data sets for comparison to the computational results. *Materials and Methods:* Three validation cases are presented. The first is a fluid sphere, for which experimental, computational and analytical results were obtained. The second is a solid-shell, fluid-filled sphere, for which experimental and computational results were obtained to determine the effect of the solid shell. The third is a representative human head. For this case, the computational model and an experimental head simulator were both developed from a CT scan of a living human head. The head simulator was built around a rapid-prototype skull using silicon organs and tissue and instrumented with accelerometers and a hydrophone. *Results:* Experimental, computational and analytical results were all in good agreement for the fluid sphere test case, proving the validity of the experimental technique and the computational technique for fluid modeling. While general agreement was obtained for the other two cases, specific discrepancies in the results are outlined and limitations of the model are discussed. *Conclusions:* A computational acoustic propagation model has been validated against a comprehensive set of experimental data. *Funding Source:* Air Force Office of Scientific Research (12 min.)

11-3 Simulation of bone conducted sound pathways to the outer and middle ear*

Margaret G. Wismer, William D. O'Brien

Affiliation: Bioacoustics Research Laboratory, University of Illinois at Urbana-Champaign

ABSTRACT

A project to determine bone conducted sound pathways to the inner ear has been sponsored by the Air Force in an effort to reduce hearing loss in personnel working in high noise environments. The study includes a computer simulation, in 3D, of an acoustic pulse wave propagating through and around a human skull. Numerical 3D simulations are benchmarked with known analytic results in order to verify accuracy. The pulse center frequency can be varied in order to identify how frequencies affect the vibrations of the skull. The program is used to validate an experimental mapping of the skull in which the response in the inner ear, with and without hearing protection, is measured as function of transducer input location at different external head locations and center frequency. An FETD algorithm written in MPI and executed on highly parallelized clusters is used to achieve these results efficiently. The mesh, on which the code operates, is a uniform grid of 8 node brick elements. Thus the program can directly operate on any digitized image (in 2D) or a list of digitized images (in 3D) in which each image is a single slice of a 3D volume. (12 min.)

11-4 Acousto-elastic integral equation based numerical simulation tools for analysis of mechanisms of energy transfer to the middle ear and for high-noise protection device design

Elizabeth H. Bleszynski, Marek Bleszynski, Thomas Jaroszewicz

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ABSTRACT

We describe progress in the development and applications of numerical simulation tools designed to (a) investigate mechanisms of energy transfer to cochlea through air- and bone-conduction path-ways and to (b) assess effectiveness of suitable noise protection devices. Our approach employs a recently implemented acousto-elastic integral equation solver, capable (through the use of non-lossy Fast Fourier Transform (FFT)-based matrix compression algorithm and parallelization on distributed-memory systems) of accurate large-scale numerical simulations with anatomically realistic models of the human head, discretized with several million of tetrahedral elements. Recently added new solver features (including treatment of shear waves, described in terms of node-based linear elements) enable us to analyze detailed aspects of acoustic/elastic wave interaction with the human head with significant accuracy and efficiency. The underlying formulation of the considered

acoustics and elasticity integral equation solver allows efficient simulations of problems characterized by large material density contrasts, such as occurring for a biological tissue (density close to that of water) immersed in air as well as the presence of complex structures involving thin sheets of biological tissue. In such problems only a small fraction of the incident wave energy penetrates inside the object. As a consequence, more conventional integral-equation approaches encounter difficulties (related to ill-conditioning) in accurate determination of the solution in the object interior. In particular, our approach (i) Facilitates examination of the relative amounts of energy transferred to the middle and inner ear directly through the outer ear, and, indirectly, via excitation of elastic waves in the skull and soft tissues, and (ii) Allows a quantitative evaluation of the effects of noise-protection devices (such as helmets, earmuffs, face covers) on the amounts of energy penetrating to the ear canal and to the interior of the head. We discuss representative applications of numerical simulations. In particular we analyze effects of the protective helmet geometry and its mechanical material properties on the pressure distribution inside the head and on its surface. This work is supported by the AFOSR. (12 min.)

11-5 Effects of ear-canal pressurization on middle-ear responses for bone and air conduction*

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Sunil Puria^{2,3,4}

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Background: In extremely loud noise environments, it is important to protect one's hearing against noise transmitted not only through air conduction (AC) but also through bone conduction (BC) pathways. The main peak of BC noise transmission spectrum is around 1.5 - 2 kHz, which is believed to be associated with the middle ear. One potential approach in mitigating this is to use ear-canal pressurization, which is known to reduce BC as well as AC hearing sensitivity. *Materials and Methods:* Umbo and stapes velocities were measured using human cadaver temporal bones in response to both shaker excitation (BC) as well as ear-canal acoustic pressure (AC) at multiple levels of ear-canal static pressure ranging between ± 400 mmH₂O. A finite element (FE) model of a human middle ear was also used to analyze the measured data. *Results:* Measurement shows up to 7-8 dB of mean BC response suppression for both umbo and stapes velocities mainly around 1-2 kHz for 400 mmH₂O of static pressure. Results indicate that this is caused by the shifting of the middle-ear resonances, which are nominally in 1-2 kHz, into high frequencies. The BC responses appear to be suppressed more in negative pressure than in positive pressure. The FE analysis suggests that this may be attributable to a difference in the distribution of

stiffening among the middle-ear components depending on the direction of pressurization. *Conclusion:* Middle-ear BC responses in the critical mid-frequency range of 1-2 kHz are significantly reduced by the ear-canal pressurization, mainly through the suppression of the middle-ear resonance effect. The present temporal bone measurement data are largely consistent with the psycho-acoustical data from the literature. *Funding Source:* Air Force Office of Scientific Research (AFOSR) under a STTR funding (contract No: FA9550-07-C-0088). (20 min.)

11-6 Failure analysis as tool for middle-ear research

Gerald Fleischer

Affiliation: Justus-Liebig-University

ABSTRACT

Auditory Research systematically collected data on accidents in man that caused noise-induced damage to hearing. In practically all cases powerful impulses close to the ear brought about this injury. Three major types of permanent damage can be recognized in the pure-tone audiogram, caused by resonances within the middle ear. (Current middle-ear models primarily include only the well-known C5-notch). Because harmful impulses have extremely different pressure-time-histories it is complicated to determine how effectively they can stimulate the three major forms of resonances. Mathematical procedures are being used to find the relation between the pressure-time-history of impulses – any impulses – and the resulting form of damage. Such analysis of data collected for man offers two ways of application: One is the improvement of functional middle-ear models, and the other is the possibility to determine the danger caused by impulses at the workplace, or everywhere else. (12 min.)

11-7 Ultrasound transmission and behavioral tuning in the middle ears of Asian frogs

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ABSTRACT

Amphibians were believed, until recently, not to hear frequencies above 5-8 kHz, possibly because the link between the tympanic membrane and the oval window consists of a single ossicle with cartilagenous extensions that should absorb high frequencies. Recent studies on Asian frogs revealed two species (*Odorrana tormota* and *Huia cavitympanum*) that communicate acoustically using ultrasound and are sensitive up to 38 kHz. In this

study we employed laser Doppler vibrometry to describe the TM's vibration response to sound in both ultrasound-hearing Asian frogs. We also used selective muscular stimulation and video imaging to document the discovery of a mechanism of behavioral control of ET closure. Our vibrometric measurements confirmed that in both species, the vibration response range of the TM extends above 35 kHz. We also found that, in *O. tormota*, contractions of the submaxillary and petrohyoid muscles cause pivoting of the anterior hyoid horn over its attachment to the skull, closing the ET. Such closure shifts the acoustic response of the middle ear, producing up to 20 dB gain above 10 kHz and up to 26 dB attenuation below 10 kHz. Mathematical modeling indicates that this spectral shift is due to the extreme reduction of the volume of air behind the TM when the ET is closed and the middle ear is isolated from the mouth. ET closure was observed to always accompany the phonatory phase of calling, suggesting a protective role against self-produced intense sound. The study of hearing in Asian frogs is not only demanding a reevaluation of the spectral limits of non-mammalian middle ears, but it also has revealed a novel mechanism of behavioral middle ear tuning in vertebrates. Supported by NIH grant no. DC-00222, the P. S. Veneklasen Research Foundation and the UCLA Academic Senate grant no. 3501 to PMN. (20 min.)

12 PRESSURE REGULATION

Moderators: Dirk Beutner, Richard L. Goode

12-1 Middle ear pressure regulation—Complementary action of the mastoid and Eustacian tube*

Michael L. Gaihede¹, Joris J.J. Dirckx², Henrik Jacobsen¹, Jef Aernouts², Morten Søvsø¹, Kjell Tveterås¹

Affiliation: 1) Department of Otolaryngology, Head and Neck Surgery, Aalborg Hospital, Aarhus University Hospital, Denmark; 2) Laboratory of Biomedical Physics, Antwerp University, Belgium

ABSTRACT

Hypothesis: Regulation of middle ear pressure (MEP) is exerted by two basic mechanisms: Eustachian tube (ET) openings and mastoid mucosa gas exchange (GE), and both of these mechanisms act complementary and actively in both positive and negative directions. *Background:* Development of negative MEP is normally perceived as a result of passive gas absorption from the middle ear and mastoid mucosa counter-regulated by intermittent openings of the ET. However, more studies have indicated that GE is bilateral and may also result in positive pressures. The development of positive MEP has hitherto been attributed to physiological changes in relation to sleep and body position, but we have

previously demonstrated that pressure changes in positive direction can also occur merely in response to smaller experimentally induced negative MEP's. Thus, it seems that smaller physiological pressure deviations can be counter-regulated in both positive and negative directions without ET openings, whereas larger pressure deviations will activate ET openings. *Materials and Methods:* In 10 normal subjects submitted to surgery for parotid tumours a catheter was introduced into the mastoid through a hole drilled in antero-lateral aspect of its tip. The catheter was connected to a transducer and a logger sampling pressure data at 10 Hz. On-line experiments were performed, where increasing MEP deviations were experimentally introduced and the resulting counter-regulation was monitored for 10 min. *Results:* In general, pressure deviations less than 1 kPa produced no ET openings, whereas larger pressures resulted in ET openings. Smaller deviations in either negative or positive directions resulted in counter-regulation in the opposite directions. Data are presented graphically at the meeting. *Conclusions:* These results indicate that MEP regulation takes place by two complementary mechanisms, where larger pressure deviations result in activation of ET openings, whereas smaller deviations can be regulated solely by active and bilateral changes in GE. (12 min.)

12-2 Connectivity Analysis of Suggestive Brain Areas Involved in Middle Ear Pressure Regulation in Humans*

Saber Sami A.K.^{1,2}, Michael L. Gaihede¹

Affiliation: 1) Department of Otolaryngology, Head and Neck Surgery, Aalborg Hospital, Aarhus University Hospital; 2) Wellcome Trust Laboratory for MEG Studies, Aston University

ABSTRACT

Hypothesis: Middle ear pressure (MEP) regulation is a part-active process that is likely to involve several components of the nervous system. *Background:* Persistent negative MEP is a major pathogenetic factor in a series of ME conditions. Aspects of central components has become increasingly important, because these conditions may be interpreted as an overall dysregulation due to impairment of its sensory-motor functions. Here, we attempted to investigate the possibility of cerebral components that could play a role middle ear pressure regulation in humans. *Materials and Methods:* Eight healthy adult subjects without any history of otological or neurological disorders participated. Multi-channel EEG experiments were conducted by stimulating the ear with a novel reliable computer controlled pressure triggering system for rapid harmonized static pressure loads of +2 kPa. Static pressures were investigated following the localization of independent component brain components. This was followed by connectivity analysis of multi-channel wavelet transformed of EEG data to yield easy interpretable time-frequency plots to describe the binding properties of the neural connections that may play a role in MEP regulation. *Results:* The connectivity analysis of middle ear static pressure stimulation gave evidence to early gamma-activity

at cerebellar locations followed by connectivity to the motor cortices in the beta band. *Conclusions:* This is suggestive of an early sensory-motor feedback mechanism in middle ear pressure regulation. Future studies in diseased ears may provide important new information about MEP regulation and have clinical implications. (20 min.)

12-3 Exchange of CO₂ in the middle ear: Is it limited by perfusion or by diffusion?*

Yael Marcusohn¹, Joris J.J. Dirckx¹, Amos Ar²

Affiliation: 1) Laboratory of Biomedical Physics, University of Antwerp, Antwerp B-2020, Belgium; 2) Department of Zoology, Faculty of Life Sciences, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel

ABSTRACT

An old debate on perfusion/diffusion limitations in the context of middle ear (ME) gas exchange was revisited using data obtained from iso-pressure measurements in different mammals. *Materials and Methods:* Exchange of CO₂ in the ME of rabbits and rats was estimated using data obtained from iso-pressure measurements of total volume changes. After initiation of a long-term anesthesia protocol the tympanic membranes were perforated. The MEs were then flushed with ambient air before closing the system and starting measurements of ME gas volume changes. It was assumed that due to the initial large gradient of CO₂ between blood and ME gas and its very high solubility and diffusivity in blood and tissue compared to O₂ and N₂, the initial volume change could be attributed to entrance of CO₂ into the ME. The data obtained was normalized to cancel effects of other processes that took place during the experiments. *Results:* It was found that the initial and maximal CO₂ flow rate into the ME $[V(\dot{i}CO_2)(\Delta t=0)]$ was ~10 times faster in rabbits than in rats. The mass specific (sp) cardiac output was 0.154 mL/(min·g) in rabbits (~2800g) and 0.259 mL/(min·g) in rats (~179.1g). The sp $V(\dot{i}CO_2)(\Delta t=0)$ was 0.109 ± 0.047 microL/(h·g) in rabbits (n=16) and 0.170 ± 0.094 microL/(h·g) (n=9) in rats. Similar ratios were found when an allometric comparison was made between the ratio of sp $V(\dot{i}CO_2)(\Delta t=0)$ (~0.64), and the ratio of sp cardiac outputs (~0.59) in rabbits and rats. *Conclusion:* If the active mucosal surface areas of MEs of rabbits and rats are directly proportional to their masses as are the masses of their hearts and mass specific cardiac outputs of rabbits and rats are proportional to the rates of blood flows in the ME mucosa, these results may support the assumption that the exchange of CO₂ in the ME of mammals is mainly perfusion dependent. (12 min.)

13 DIAGNOSTICS II

Moderators: Joris J.J. Dirckx, W. Robert J. Funnell

13-1 Differential diagnosis using forward and reverse transfer functions: Measurements and Models*

Ernst Dalhoff, Diana Turcanu, Hans-Peter Zenner, Anthony W. Gummer

Affiliation: Eberhard Karls Universitaet Tuebingen

ABSTRACT

Recently, using a custom built laser Doppler vibrometer (LDV), we have shown that distortion product otoacoustic emissions (DPOAE) can be measured as vibration of the human eardrum in vivo, and proposed to use this parameter to support a differential diagnosis of middle- and inner-ear pathologies. Here, we investigate how the reverse transfer function, defined as the ratio of DPOAE-velocity of the umbo to DPOAE-sound pressure in the ear canal, can be used to differentially diagnose middle-ear pathologies. Normal and hearing-impaired guinea pigs were anaesthetized and their pinna together with the cartilaginous part of the ear canal removed. The tip of a probe microphone was glued within 2-4 mm of the tympanic membrane. Acoustic stimulation was delivered free-field. For the vibration measurements, we mounted our LDV onto an operating microscope. Using a multi-tone stimulus, the forward transfer function (*f*-TF) of umbo velocity relative to ear-canal pressure was acquired. Using two-tone stimulation with a frequency ratio of $f_2/f_1=1.2$, we computed from the DPOAEs the ratio of umbo velocity to ear-canal pressure. Taking the values from two-tone measurements recorded with different primary frequencies in the same animal, we assemble the reverse transfer function (*r*-TF) at frequencies ranging from 0.8-20 kHz. We investigate two groups of guinea pigs that show abnormal middle ear-status: fixation of the incudomalleolar complex and static middle-ear pressure, both in different grades. We show that both groups can be diagnosed differentially based on their measured forward- and reverse-transfer function properties. Using a middle-ear model taken from the literature and adapted to the guinea pig, we show modelling of middle-ear function based on *f*-TF and *r*-TF data and use it to predict the transmission of the complete middle ear, both for the normal and pathological situations. (20 min.)

13-2 Oval and round window assessment during cochlear implantation

Sharouz Bonabi¹, Daniel Bodmer², Albrecht Eiber³, Norbert Dillier¹, Dorothe Veraguth¹, Alexander M. Huber¹

Affiliation: 1) Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital of Zurich, Switzerland; 2) ENT-Universityhospital of Basel, Switzerland; 3) Institute of Engineering and Computational Mechanics, University of Stuttgart, Germany

ABSTRACT

Background: The round and oval windows are the interfaces between the middle and inner ear. Their deflection pattern is crucial for the function of the middle ear. Although measurements in temporal bone preparations are widely used, live human measurements are difficult to perform. The goal of this study was to assess the round and oval windows in live human subjects and thereby judge the influence of cochlear implantation onto the macromechanics of the cochlea. *Material and Methods:* The study was performed between 2005 and 2007 and included 21 adult patients with profound bilateral hearing loss undergoing cochlear implantation. A scanning laser Doppler interferometer measuring system connecting to an operating microscope with a built in camera was used. Scanning measurements of round and oval windows vibration was performed as a baseline using a scanning Laser Doppler interferometer. Then the cochlea was opened and the CI electrode was inserted. The assessment of the round window vibrations was then repeated with the same Laser position and angulations. *Results:* Results of the baseline measurements are comparable with the known figures from temporal bone preparations. At low frequencies the round window vibrates in one mode. At higher frequencies a more complex pattern is seen. There is no clear trend of displacement and phase difference before and after insertion of an electrode over all measurements. *Conclusions:* Round window deflection shape measurements were conducted for the first time in live human subjects. According to our results there are no significant changes between the vibration patterns of the round window membrane before and after the electrode insertion. Our results provide evidence that even a large electrode does not alter the cochlear macromechanics to a point beyond of clinical relevance. (12 min.)

13-3 The effects of ossicular chain pathology and cartilage placement on the tympanic membrane to the motion of the tympanic membrane evaluated with time-averaged holography*

Antti A. Aarnisalo^{1,2}, Jeffrey T. Cheng^{1,2}, Michael E. Ravicz¹,
Cosme Furlong^{1,3}, Saumil T. Merchant^{1,2}, John J. Rosowski^{1,2}

Affiliation: 1) Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, Boston MA; 2) Department of Otolaryngology, Harvard Medical School, Boston MA; 3) Department of Mechanical Engineering, Worcester Polytechnic Institute, Worcester MA

ABSTRACT

Hypothesis: We assess the clinical applicability of computer-assisted Opto-Electronic Holography (OEH) using human temporal bones. *Background:* OEH produces time-averaged holograms (TAH) that describe the magnitude of motion of the tympanic membrane (TM). We have studied TAH fringe patterns after ossicular fixations and mock TM cartilage reconstruction. *Materials and Methods:* TAH (500 Hz-12 kHz) were gathered in (i) normal cadaveric temporal bones, (ii) after positioning of cartilage grafts (0.5 or 1 mm thick ovals) to the medial TM surface in the postero-superior quadrant (either in contact with the bony annulus or not), (iii) after malleus fixation, (iv) after reversal of the fixation, (v) after stapes fixation and (vi) after incudostapedial joint interruption. Stapes velocity (V_s) was measured concurrently with laser Doppler vibrometry. *Results:* After ossicular fixations, higher than normal sound pressure levels are required to see TAH fringe patterns with sound frequencies ≤ 1 kHz and V_s was also decreased. Little difference in fringe patterns is seen between the fixed and normal states at frequencies above 3 kHz. Interruption of the incudostapedial joint altered fringe patterns at all studied frequencies and reduced V_s to artifact levels. The placement of cartilage on the TM produced little change in TM displacement at frequencies below 4 kHz. Above 4 kHz, TM motion was reduced, especially over the grafted TM, with greater effects seen for the 1 mm thick cartilage. Contact of the cartilage with bone of the external canal made no difference in TM motion or V_s . *Conclusions:* OEH can identify how changes in ossicular load or cartilage placement affect the motion of the TM, and is a promising technique to evaluate the causes of conductive hearing loss and optimize techniques of tympanoplasty. Work supported by NIDCD and a donation from L. Mittal. (12 min.)

13-4 Measures of the Auditory Conductive Mechanism for High Frequencies*Gerald R. Popelka¹, Goutham Telukuntla¹, Sunil Puria^{1,2}

Affiliation: 1) Department of Otolaryngology-HNS, Stanford University, Stanford CA 94305; 2) Department of Mechanical Engineering, Stanford University, Stanford CA 94305

ABSTRACT

Hypothesis: Auditory conductive mechanism function for frequencies >6000 Hz can be measured accurately with standard air conduction thresholds and bone conduction thresholds obtained with a novel magnetostrictive bone conduction transducer. *Background:* Currently (ANSI-2004), hearing sensitivity by bone conduction is measured over a narrower frequency range (125–6,000 Hz) than by air conduction (125–20,000 Hz). This limitation, due to inadequacies of current electrodynamic bone conduction transducers, prevents assessment of conductive function in the high frequency range and severely limits investigation of surgical intervention. The purpose of this study is to evaluate a novel magnetostrictive transducer for measuring conductive mechanism function in the high frequency region. *Materials and Methods:* Hearing sensitivity was measured by air conduction from 250–12,500 Hz and by bone conduction from 250–6000 Hz in nine subjects with hearing levels from -5 dB HL to 90 dB HL (ANSI-2004). All had normal middle-ear function, no conductive loss for frequencies up to 6000 Hz and presumed normal conductive function for frequencies >6000 Hz. Hearing sensitivity by bone conduction in the high frequency range (6000–12,500 Hz) was measured with a novel magnetostrictive transducer (Teac Filltune). *Results:* The average difference between air- and bone-conduction thresholds was negligible (1.1 dB) for standard frequencies and only slightly larger (-7.2 dB) for high frequencies. The variability of this difference for high frequencies (sd=6.7dB) was almost twice as large as for the standard frequencies (sd=3.6 dB) likely due to more variable air conduction measures and uncontrolled bone-conduction variables such as coupling force. There was sufficient output to obtain thresholds at all but two frequencies in one case. *Conclusions:* A novel magnetostrictive bone conduction transducer has sufficient output to accurately measure auditory conductive mechanism function for frequencies from 6000–12,500 Hz and hearing levels from -5 to 85 dB HL. *Funding Source:* NIDCD of NIH R01 DC05960. (12 min.)

14 ME HEARING AIDS II

Moderators: Thomas Beleites, Jin Ho Cho

14-1 Comparison of the frequency response of acoustic and implantable hearing aids

Hannes Seidler, Matthias Bornitz, Nikoloz Lasurashvili, Thomas Zahnert
Affiliation: Clinic of Otorhinolaryngology, Department of Medicine, Technical University, Dresden, Germany

ABSTRACT

Implantable hearing aids are gaining more and more importance for the technical rehabilitation of hearing impairment since several years. Along with the growing experience in surgery the technology has been also improved including the sensors and actuators. In parallel the traditional hearing aids developed likewise: new transducer, an efficient signal processing, changed coupling etc. For the clinical application and an optimum advise of the patients it is important to know the advantages of both systems. This investigation refers basically to the measurable differences of the frequency response. Therefore, we developed a procedure to measure the resultant signals in the Cochlea for different sensors and signal processing. In the contribution the approach, the measurement set-up and the selection criterion are described. The first investigations point to the fact that implantable hearing aids show a broader and constant frequency response according to kind of the coupling. On the other hand, conventional hearing aids achieve partially higher signal levels. (12 min.)

14-2 A Middle Ear Implant Using a Piezoelectric Stack with Mechanical Amplification

*Eric W. Abel*¹, Robbie C. Brodie¹, Zhigang Wang¹, Robert P. Mills²,
Duncan J. Bowyer²
Affiliation: 1) University of Dundee, UK; 2) University of Edinburgh, UK

ABSTRACT

Hypothesis: In recent years great efforts have been made to develop a successful middle ear implant (MEI). Electromagnetic drivers have on the whole been more successful than those using piezoelectric crystal actuators. It should, however be possible to take advantage of piezoelectric technology to design an effective driver for an MEI. *Background:* It is a challenge to the designer of a middle ear implant to create a driver that can generate sufficient levels of vibration of the ossicular chain across the audio frequency range, couple well mechanically so that energy losses are minimized and avoid acoustic feedback to the microphone. The next generation of implants will be totally implantable, so low power

consumption will be an important feature for releasing MEI users from the daily task of having to attend to their hearing device. Piezoelectric actuators tend to use less power than electromagnetic devices and can have other advantages, such as being more compatible with MRI. It is however difficult to achieve a good combination of adequate driving force and sufficient displacement. A piezoelectric crystal stack with a mechanical amplifier to increase displacement gain is being investigated. *Materials and Methods:* The miniature piezoelectric stack has dimensions of 2x0.9x0.4 mm and contains 51 layers, each 30 μm thick. The mechanical amplifier consists of a single flexible component. As the stack elongates, the frame flexible expands. The gain is between 6dB and 12dB according to the design. A piston attached to the frame couples to the target. The device may be mounted on the ossicular chain and coupled to the stapes footplate, or used on the round window. Bench and temporal bone tests to date have used a computer driven voltage source. An implantable electronic module nearing completion comprises an implantable battery with charge control circuitry, a sound processor and wireless units for remote programming and user control. *Results:* Various iterations of the actuator unit have been tested on the bench and in temporal bones. On the bench the current design produces the equivalent of about 110dB at 4V up to about 7 kHz. In temporal bones, the results can approach this level sometimes but not consistently. Design improvements are being made to improve coupling of the actuator to the stapes. Round window tests are in progress. *Conclusions:* The performance of the actuator has been shown to be adequate for moderate to severe hearing loss and can be attached either to the ossicular chain or to the round window. Methods to improve coupling efficiency on the ossicular chain are currently being undertaken. *Funding Source:* Various charitable sources, Scottish Enterprise, Glasgow, UK (Proof of Concept fund) and most recently private investment. (12 min.)

14-3 The application of the fully implantable Carina system in patients with atresia auris congenita

Stefan Mattheis¹, Carolin Neumann², Ralf Siegert²

Affiliation: 1) ENT Department, University Clinic of Essen, Germany; 2)

Department of ORL, Head and Neck surgery Prosper-Hospital, Recklinghausen, Germany

ABSTRACT

Atresia auris congenita causes a conductive hearing loss with an air- bone gap of 60 dB. Conventional bone conducting hearing aids, bone anchored hearing aids are standard treatment options. 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. Although the results of a surgical construction of the sound conducting apparatus improved, there still remains an air-bone gap that makes conventional hearing aids necessary in some

patients. Our study has the aim to improve the audiological rehabilitation of those patients by using the fully implantable Carina device. We modified the transducer, by connecting it to a titanium PORP, known from middle ear surgery. By placing the PORP on the stapes tip, vibrations of the device are transmitted to the inner ear. Alternative stimulation of the footplate or the round window is possible. From January 2006 to October 2008 we implanted the Otologics Carina device in 12 patients (6 male, 6 female) with ages from 13 to 40 years. After activation and fitting of the devices we see an improvement of the sound-field thresholds up to 50 dB HL. The average functional gain in a three frequency pure tone average is about 34 dB HL. The discrimination rate of monosyllables in speech testing increases up to 75 %. Patient satisfaction was controlled by APHAB and a questionnaire. This technique seems to provide a new alternative for the audiological rehabilitation of patients with severe malformations of the middle ear. (12 min.)

14-4 TORP-Vibroplasty – experimental evaluation and clinical results

Dirk Beutner¹, Jan-Christoffer Luers¹, Matthias Bornitz², Thomas Zahnert², Karl-Bernd Hüttenbrink¹

Affiliation: 1) Dept. of Otorhinolaryngology, Head and Neck Surgery, University Hospital Cologne; 2) Dept. of Otorhinolaryngology, Head and Neck Surgery, University Hospital Dresden

ABSTRACT

Background: Surgery can often eradicate chronic middle ear disease, but in many cases, social hearing can not be restored even after multiple revision tympanoplasties. Placement of an implantable hearing aid with its advantage of an unoccluded ear canal, irrespective of middle ear function, seems to be a promising alternative. **Material and Methods:** Temporal bone experiments resulted in the development of a new titanium-clip holder for a Vibrant-integrated TORP-assembly with placement on the footplate. Six patients with permanent severe combined hearing loss were implanted with this device after multiple revision tympanoplasties. **Results:** Placing a transducer directly on the footplate via a rod-transmission gave a better gain for the high frequencies than in the round-window location. The acoustic results of the patients showed an improved gain in speech understanding. Furthermore, assessment of benefit and satisfaction using the standardized International Outcome Inventory for Hearing Aids was superior to conventional hearing aids in subjective and in audiometric terms. **Conclusion:** The concept of a TORP-vibroplasty establishes a straightforward procedure in the tympanic cavity similar to a normal tympanoplasty. The open ear canal and its superior acoustic performance offer a promising perspective for revision surgeries in cases of incurable middle ear dysfunction. (12 min.)

14-5 Development of an implanted bone-conduction hearing aid using giant magnetostrictive material*

Takuji Koike¹, Kensei Yamamoto¹, Michihito Aoki¹, Kyoji Homma¹, Naohito Hato², Sho Kanzaki³

Affiliation: 1) Department of Mechanical Engineering and Intelligent Systems, The University of Electro-Communications, Tokyo, Japan; 2) Department of Otolaryngology, School of Medicine, Ehime University, Ehime, Japan; 3) Department of Otolaryngology, School of Medicine, Keio University, Tokyo, Japan

ABSTRACT

To circumvent some of the disadvantages of conventional hearing aids such as sound distortion, feedback, and cosmetic factors, implantable hearing devices have been developed. However, these hearing devices also have problems such as insufficient output at high frequencies, inflammation, and so on. In this study, a new subcutaneously implanted bone-conduction hearing aid with an external unit and an internal unit was proposed. The external unit consists of a microphone, a speech processor, and a transmitting coil, which send the sound signals and energy to the internal unit by generating a magnetic field. The internal unit consists of a receiving coil, a driving coil, and a vibrator made of giant magnetostrictive material (GMM), which deforms its body by changing the magnetic field. The internal unit is surgically embedded in the temporal bone under the skin and vibrates the skull when the magnetic flux is applied by the external unit. For the first stage in the development of the new bone-conduction hearing aid, a prototype was made and its fundamental properties were examined. AM signals (the modulating frequency was 0.25 - 8.0 kHz and the carrier pulse wave was 40 kHz) were applied to the transmitting coil, and the force generated by the vibrator was measured with a piezoelectric force sensor and a laser Doppler velocimeter. The high-frequency carrier signal was efficiently transmitted from the transmitting coil to the receiving coil, and a component of audible frequency was detected with high intensity according to the modulating frequency. This result suggests that the transducer had a function of self-demodulation, and a very simple structured implanted bone-conduction hearing aid can be developed using GMM. This research was supported by Japan Science and Technology Agency (JST). (12 min.)

14-6 A Totally Implantable Hearing System—TIHS*

Rong Z. Gan¹, Chenkai Dai¹, Xuelin Wang¹, Don Nakmali^{1,2},
Mark W. Wood²

Affiliation: 1) University of Oklahoma, Norman, OK; 2) Hough Ear Institute,
Oklahoma City, OK

ABSTRACT

Implantable middle ear hearing devices are emerging as an effective technology for patients with mild to moderately severe sensorineural hearing loss. Several devices with electromagnetic or piezoelectric transducers have been investigated or developed in the US and Europe since 1990. This paper reports on a totally implantable hearing system (TIHS) under investigation in Oklahoma. The TIHS consists of an implant transducer (magnet) placed on the middle ear ossicles, an implantable coil placed under the ear canal wall, an assembly of implantable microphone, a sound processor and rechargeable battery, and a remote control unit. The interaction between electromagnetic fields of the coil and implant magnet causes the ossicles to vibrate. Its design incorporates bioengineering approaches based on the finite element (FE) model of the human ear and analysis of electromagnetic coupling of the transducer. The tests conducted to characterize the device's performance across the auditory frequency range included: (1) mass loading effect on residual hearing with the passive implant, (2) effectiveness of the electromagnetic coupling between implanted coil and magnet, and (3) a function characterization of whole unit in response to acoustic input across the skin. The results indicate that the TIHS tested in human cadaver ears or temporal bones shows satisfactory performance of the system. The three-dimensional computational model can be considered as a standard tool for design and functional characterization of middle ear implants and implantable devices. (Supported by Oklahoma Center for Advancement of Science & Technology.) (12 min.)

14-7 The application of the fully implantable Carina system in patients with moderate to severe sensorineural hearing loss

Carolin Neumann¹, Stefan Mattheis², Ralf Siebert¹

Affiliation: 1) Department of ORL, Head and Neck surgery Prosper-Hospital, Recklinghausen, Germany; 2) ENT Department, University Clinic of Essen, Germany

ABSTRACT

The fully implantable Carina is a hearing prosthesis designed to address the amplification need of adults, 18 years of age or older, with moderate to severe sensorineural hearing loss by mechanical stimulation of the ossicles. The system is fully implantable, allowing the device to be used in all normal environments and activities. Our study has the aim to improve the audiological rehabilitation of those patients by using the fully implantable

Carina device. A titanium ball-shaped PORP is fixed to the transducer. By connecting the ball to the incus, vibrations of the device are transmitted to the inner ear. From January 2006 to October 2008 we implanted the Otologics Carina device in 6 patients (2 male, 4 female) with sensorineural hearing loss, ages from 38 to 70 years. After activation and fitting of the devices we see an improvement of the sound-field thresholds up to 40 dB HL. The average functional gain in a three frequency pure tone average is about 26 dB HL. The discrimination rate of monosyllables in speech testing increases up to 80 %. Patient satisfaction was controlled by APHAB and a questionnaire. This technique seems to provide a new alternative for the audiological rehabilitation of patients with moderate to severe sensorineural hearing loss if other rehabilitations failed. (12 min.)

14-8 Long-term follow up study of Rion implantable hearing aid

Kiyofumi Gyo¹, Naohito Hato¹, Masahiro Komori², Naoaki Yanagihara²

Affiliation: 1) Ehime University; 2) Takanoko Hospital

ABSTRACT

Objective: The aim of this study is to evaluate long-term durability and functional stability of Rion implantable hearing aid (IHA) and to discuss optimal condition for success implantation of such middle ear device. *Patients:* Of the 39 patients with implantation of IHA during the last 12 years between 1985 and 1997, 32 patients who were followed up for more than 10 years were the subjects of this study. In the rest of 7 patients, 2 were died of unrelated diseases and 5 were lost for follow up. *Results:* Of the 32 patients, 11 have used the device for more than 10 years. In the rest of 21 patients, the device was removed in 11 cases, re-implanted and used in 4, re-implanted but removed later in 3, and no longer used in 3. Therefore, 15 patients still use the devices in their daily lives and take advantage of a comfortable sound. Complications of the implant revealed during long-term follow up were skin fistula in 5 cases, severe retraction pocket in 5, incidence or recurrence of cholesteatoma in 4, and middle ear infection in 3. Device troubles were also noted concomitant with the above complications; decrease in vibrator sensitivity in 8 cases and disconnection of the vibrator in 2. *Conclusions:* IHA works well for more than 10 years in some patients, however, long-term implantation of such device remains difficult, especially in ears with history of chronic middle ear inflammation. Our experience showed that careful preoperative evaluation of the middle ear condition would be a key for long-term success of middle ear implant. (12 min.)

15 COMMUNITY DISCUSSION

Moderators: Karl-Bernd Hüttenbrink, Stefan Stenfelt

Please post your Community Discussion questions on the Discussion Site prior to this session: <http://memro2009.stanford.edu/discussion>.

POSTERS

Moderators: Samuel N. Merchant, Gerald R. Popelka

P-1 Realistic morphological 3-D model of the gerbil middle ear, including bone and soft tissue structures*

Jan A.N. Buytaert, Manuel Dierick, Patric Jacobs, Joris J.J. Dirckx

Affiliation: University of Antwerp – Laboratory of BioMedical Physics

ABSTRACT

Finite element modelling (FEM) of the middle ear (ME) is an established method to simulate and understand its complex behaviour. In order to improve the realism of these simulations, correct morphological data are needed as input for FEM calculations. The current 3-D ME models use rudimentary shapes of the ossicles and hardly incorporate any soft tissue structures. Most models originate from X-ray micro-computer tomography (μ CT), which mainly shows the ME ossicles with modest resolution. Attempts have been made to also obtain shape data of ME fascia and muscles from such recordings, but the low contrast leads to poor quality. Other authors have used histological sections as a source for their 3-D models. This provides high in-plane resolution for these cross sections, but the specimen is destroyed and image registration is difficult. We combine three-dimensional data from state-of-the-art high-resolution μ CT recordings on gerbil, with data from high-resolution orthogonal-plane fluorescence optical-sectioning microscopy (HROPFOS) on the same specimen. The new μ CT setup yields accurate data on the three-dimensional shape of the surrounding bone and ossicles, while the HROPFOS data accounts for the soft tissue structures. The result of merging the high-quality datasets from two different techniques is a complete and high-resolution morphological model of all functional structures in the gerbil ME. The model data will be made freely available on our website for educational and research purposes.

P-2 Nonlinearity in eardrum vibration as a function of frequency and sound pressure*

Johann R.M. Aerts, Joris J.J. Dirckx

Affiliation: Laboratory of BioMedical Physics, University of Antwerp, Belgium

ABSTRACT

It is generally accepted that the middle ear acts mainly as a linear system for sound pressures up to 130 dB SPL in the auditory frequency range. However, at quasi-static pressure loads a strong nonlinear response has been demonstrated. Consequently, small nonlinear distortions may also be present in the middle ear response in the auditory frequency range. A new measurement method has been developed to quickly determine vibration response, nonlinear distortions and noise level of acoustically driven biomechanical systems. Specially designed multisines are used for the excitation of the test system. These are periodic signals with excited harmonics in a certain frequency range and non-excited harmonics to detect nonlinear distortions. The method is applied on a gerbil eardrum for sound pressures ranging from 78 to 120 dB SPL and for frequencies ranging from 125 Hz to 8 or 16 kHz. The experiments show that nonlinear distortions rise above noise level at a sound pressure of 96 dB SPL, and they grow as sound pressure increases. Post-mortem changes in the middle ear influence the nonlinear distortions rapidly until a stabilization occurs after approximately 3 hours.

P-3 Active Middle Ear Implants (AMEIs) in Patients with Mixed or Conductive Hearing Losses—A Review and Analysis of the Literature

Mario D. Wolfram, Jane M. Opie, Christine Mühlöcker

Affiliation: VIBRANT MED-EL Hearing Technology GmbH, Innsbruck, Austria

ABSTRACT

Purpose: To review and analyze current literature on safety and efficacy outcomes with AMEIs in patients with mixed or conductive hearing loss. *Background:* AMEIs were originally described for treatment of conductive or mixed hearing loss in the 1970s. However, early designs were limited in their success either because of the transducer materials used or because of the relatively large distance between the driver and transducer. As a consequence, clinicians focused on implanting AMEIs in persons with sensorineural hearing loss. Recently, surgical techniques have been modified such that AMEIs are again being applied to conductive and mixed hearing losses. *Materials and Methods:* A Pubmed search was conducted to retrieve all relevant publications available since 2006 on active middle ear implants in patients with conductive or mixed hearing loss. In addition, proceedings from scientific congresses were reviewed to obtain abstracts on the topic. More than 25 scientific sources, representing data on more than 170 implanted ears, could be identified. Surgical techniques, pre- to postoperative hearing thresholds, aided sound field thresholds,

functional gain, speech reception thresholds, word understanding and medical and surgical complications were compared. *Results:* An analysis of the publications showed that, in general, postoperative aided thresholds, functional gain, speech reception thresholds, and word recognition scores improved as compared with preoperative performance. The reported medical and surgical complication rate was low. *Conclusion:* The literature suggests that AMEIs may be applied to patients with conductive or mixed hearing loss with good hearing outcomes and little risk. *Funding Source:* None.

P-4 A clinical method for calibration of bone conduction transducers to measure the mastoid impedance*

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ABSTRACT

When using bone vibrator transducers for clinical measurements, the transfer of energy from the bone driver depends on the impedance match between the driver and the load (human mastoid or otherwise) to which the driver will be applied. Any deficiencies in this impedance match will degrade the quality of the clinical measurements. The aim of this research is to develop a simple absolute field calibration method of the bone driver based on F.V. Hunt's ("Electroacoustics", 1982) model of an electroacoustic transducer. Hunt's model describes the driver using three frequency-dependent parameters: the electrical impedance Z_e , mechanical impedance z_m , and transduction coefficient T . Knowledge of these three impedance properties of the driver facilitates measurements of arbitrary load impedances and the frequency dependence of the transmitted energy. From measurements at the driver's electrical terminals with the driver in known loading conditions (such as a simple mass load), the driver electrical impedance can be determined. The approach proposed here is to determine $Z_e(f)$, $z_m(f)$ and $T(f)$, for a Radio ear BA71 bone driver, from simple mass-loaded electrical measurements. Once these functions are known, an arbitrary mastoid impedance may be determined from measurements of the driver current. Results using this method will be presented.

P-5 Micro-indentation to determine middle ear ossicles elasticity parameters*

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ABSTRACT

When creating a finite element model (FEM) of the middle ear (ME), the ossicles can be modelled as rigid bodies or as linear elastic materials. General parameters can be used, which are measured on larger bones, like the femur. The cochlea is known to be one of the hardest bones in the body, so also for the ossicles it is not straightforward to use literature values obtained from other types of bone. In animal models, parts of the auditory ossicles are extremely thin. In order to obtain highly realistic modelling of these systems, it is not clear if the rigid body approach is sufficient. A way to test this, is to implement correct material properties for ossicle elasticity in the ME FEM and see if the ossicle deformation has a significant effect in different frequency ranges. Two important input parameters to obtain such realistic modelling are the elastic modulus and the strength of the ossicles themselves. We have developed a micro-indentation system based on the Oliver-Pharr method, which is widely used in material sciences. We apply indentation cycles with micron-accuracy and record the induced force with high resolution. The indentation needle is a steel-cylinder with a diameter of 120 micrometers allowing experiments on very small objects. The measured indentation depth and resulting force are used to calculate stiffness and to determine material parameters. The system was tested on several materials with known parameters in order to validate the technique, and then used to determine the elasticity parameters of incus and malleus. No significant differences between measurement locations was found, and we measured a Young's modulus of 16 ± 3 GPa. *Funding Source:* J.A.M.S. was funded by an Aspirant fellowship of the Research Foundation – Flanders.

P-6 The new tool of ossicular mobility tester using an electromagnetic driver and a piezoelectric sensor

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ABSTRACT

Hearing does not always improve satisfactorily after tympanoplasty. The outcome depends on a variety of factors such as middle ear disease, tubal function, the surgeon's skill, and the type of ossicular reconstruction. The mobility of the ossicles, especially of the stapes, is thought to be one of the most critical factors affecting postoperative hearing. Most otologic surgeons assess the ossicular mobility by placing an ear pick on the ossicle and activating it manually. This maneuver provides only a rough estimate, and the results are subjective. Although conventional ossicular vibration tester using a pair of ceramic elements provided

important information on ossicular mobility, clinical assessment of the device revealed these drawbacks: the ceramic tip was so fragile, the device had to be held stable for 8 s, measurements were often influenced by electric noise. Since 2003, we have developed a new ossicular mobility tester using an electromagnetic driver and a piezoelectric sensor. This device consists of three components: a probe shaft with a curved tip to be attached to the target ossicle, a vibration exciter to activate the probe, and a piezoelectric sensor to detect vibrations of the probe. These components are encased in a stainless steel holder, allowing easy hand manipulation during ear surgery. The device is a computer-controlled system by Labviewovtv32eh, and it overcomes most of the drawbacks of our previous system. The results are presented as the ratio of the ossicular resistance (ROR) to a reference value as a percentage: <40% indicates normal mobility, 40-70% is decrease in mobility and >70% is fixed. The criteria was derived from our report. (Hato et al., 2006)

In 2003 MEMRO, we have reported preliminary results in four patients. Now, we reports results adding some cases.

P-7 Design and Implementation of Acoustic Sensor for Compensating Damping Effect of Skin using FEA simulation

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ABSTRACT

Hearing aids are being widely used for hearing impaired person. However, it has been shown that the conventional hearing aids are insufficient for compensating sever and profound sensorineural hearing loss due to the problems such as acoustic feedback, limited amplification, and so on. Recently, implantable hearing devices (IMEHDs) have been developed to solve these problems. IMEHDs are composed of an implantable microphone as an acoustic sensor, a signal processing unit and a vibration transducer as an actuator.

Among these components, a sensitivity of an implantable microphone as acoustic sensor is very important factor because the input sound signal is detected by acoustic sensor. Normally, an acoustic sensor has poor frequency response characteristics in high frequency bands of acoustic signal due to the high frequency attenuation effect of skin after implantation in human body. In this paper, the acoustic sensor is designed to reduce the high frequency attenuation effect of a skin by putting its resonance frequency at the attenuated range through a finite element analysis (FEA) simulation. The designed acoustic sensor through

the simulated results has been fabricated by manufacturing process using bio-compatible materials and the acoustic sensor is sealed hermetically using laser because the acoustic sensor is implanted on the human body. A sensitivity of an implemented microphone is measured in free field and the in-vivo experiment is also performed with a mouse. Thorough the comparison experiment in free field with the in-vivo experiment, it has been verified that the designed implantable microphone has a resonance frequency around the starting part of the attenuated range and reduces the attenuation effect. *Acknowledgement:* This study was supported by a Ministry of Knowledge Economy, Republic of Korea and this study was supported by the Brain Korea 21 Project (BK 21).

P-8 Development of a Fully-Implantable Middle Ear Hearing Device in Korea

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ABSTRACT

Despite the development of semi-implantable middle-ear hearing devices (SIMEHDs) with a high quality sound delivery in several countries, these devices are not so attractive to hearing-impaired patients due to the discomfort of wearing an external device containing an audio processor and battery. Thus, it is expected that fully-implantable middle-ear hearing devices (FIMEHDs) will soon be available with the advantages of complete concealment, easy surgical implantation, and low power operation to resolve the problems of SIMEHDs. Over the last 6 years, a Korean research team at Kyungpook National University has developed an FIMEHD called ACROSS based on a differential floating mass transducer (DFMT). The main research focus was functional improvement, biocompatibility, miniaturization, and a low-power operation. This paper shows the F-IMEHD being developed in Korea and the current status of the F-IMEHD, overall system architecture, functions and experimental results using the ACROSS. In this year, the ACROSS has been developed 8th version, ACROSS v1.8. The ACROSS v1.8 consists of an audio signal processor unit, a vibration transducer, an implantable microphone, a wireless recharging system, and a RF based wireless remote controller. The several tests have been performed to obtain a safety and effectiveness data of ACROSS v1.8. At first, the effectiveness tests of the ACROSS v1.8 have been performed using the cadaver in last February. Next, the biological safety tests for material have been performed and the tests for electrical safety, chemical safety, EMI/EMC, etc. also have been performed. Through the several tests, a safety and effectiveness

of ACROSS are verified. Acknowledgement: This study was supported by a Ministry of Knowledge Economy, Republic of Korea and this study was supported by the Brain Korea 21 Project (BK 21).

P-9 Effect of absence of malleus on ossiculoplasty in human temporal bones

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ABSTRACT

Hypothesis: We evaluated the effect of malleus presence or absence on middle ear sound transmission after middle ear reconstruction in a temporal bone model. *Background:* The malleus handle is thought to allow proper adaptation of a fascia graft and improve the stability of a reconstructed ossicular chain. However, some studies have found that the presence of the malleus is not an important contributor to the post-surgical hearing outcome. *Methods:* The velocity of the center of the stapes footplate was measured using a laser Doppler vibrometer in response to a constant sound pressure input at the tympanic membrane over the frequency range 0.1 to 10 kHz. After baseline measurements in eight intact temporal bones, the incus was removed and replaced with a sculpted incus between the mid-malleus handle and stapes head, and the measurements repeated. Then, the malleus was removed and another sculpted incus was placed between the tympanic membrane and stapes head, and the two test conditions compared. Furthermore, to assess the influence of interposed cartilage, cartilage pieces of three different diameters were inserted between the tympanic membrane and the sculpted incus and the three test conditions again compared. *Results:* Reconstruction without a malleus produced better results at frequencies above 4.5 kHz, while the results tended to be slightly worse at 0.6 to 3.0 kHz. However these differences were not statistically significant. In the cartilage experiments, the large-diameter cartilage was the worst at 0.25 kHz and 0.5 kHz but better than the medium-diameter cartilages at 3.0 kHz and 4.0 kHz ($p < 0.05$). *Conclusion:* Absence of the malleus impaired middle ear sound transmission slightly in the mid-frequencies and improved it at higher frequencies compared to reconstruction with the malleus present. *Funding Source:* None.

P-10 Hearing improvement with laser contraction myringoplasty for tympanic membrane atelectasis

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ABSTRACT

Tympanic membrane atelectasis is the loss of normal contour and elasticity of the tympanic membrane as a result of persistent negative middle ear pressure. Ventilation of the middle ear cavity can correct the atelectasis in some cases, but the tympanic membrane often remains atelectatic with conductive hearing impairment in many cases. Our hypothesis is minimally invasive contraction myringoplasty using CO₂ laser is effective for treatment of tympanic membrane atelectasis and conductive hearing impairment. This is a preliminary report of two cases succeeded in hearing improvement with the laser myringoplasty. Case 1 was 18 years old, male. He suffered hearing disturbance after recurrent otitis media with effusion. Right tympanic membrane was treated using CO₂ laser (OtoLAM, LUMENIS). The laser power setting was 3.0 W in a spiral shaped beam with a spot size of 1.2 mm. This procedure results in immediate contraction and tightening of the tympanic membrane without the perforation. Hearing threshold improved from 29 to 22 dB SPL after the procedure. Case 2 was 58 years old, female. She suffered hearing disturbance with right tympanic membrane atelectasis after operation of chronic otitis media. Hearing threshold improved from 43 to 32 dB SPL after the laser myringoplasty. These clinical cases are first report of hearing improvement after laser contraction myringoplasty for the tympanic membrane atelectasis.

P-11 Contribution of static force and oscillator placement in bone conduction sensitivity*

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ABSTRACT

Hypothesis: Bone conduction hearing sensitivity differs as a function of oscillator placement and is independent of the level of static force. *Background:* In clinical tests of bone-conduction hearing, sensitivity is better if the oscillator is coupled to the listener's mastoid rather than to the forehead. This may be due to the placement location of the oscillator or the increase in static force that is applied for coupling. This may be due to the placement location of the oscillator or the increase in static force that is applied for

coupling. Scientific understanding about the relation, if any, between placement location and contact force of an oscillator for bone conduction hearing is needed for future applications such as enhanced speech understanding in noise via bone-conduction. *Methods:* One group of 12 young, normal hearing adults with small head sizes and one with large head sizes participated. Bone-conduction hearing thresholds were determined across the frequency range of 250-8000 Hz, in one-sixth octave bands, with a standard bone oscillator for three placement locations: forehead, and left and right mastoid regions. At each location and across all participants the static force applied to the oscillator was held constant at 2N and at 5N, with the use of customized headbands. In addition, thresholds for each location were determined with the standard clinical headband, that applies a static force related to an individual's head size and placement location of the oscillator. *Results and Conclusions:* Group data for listeners with small heads supported the hypothesis and demonstrated greater hearing sensitivity at the mastoid location. Group data for listeners with large heads did not support the hypothesis; sensitivity was greater at 2N compared to 5N and less sensitive for the right mastoid compared to the forehead. Across both groups the thresholds obtained with the standard headband, used in clinical application, was independent of the static force. *Funding Source:* USAF, AFRL FA9550-06-1-0128.

P-12 Our Experience with the Soft Clip Piston in Stapedotomy*

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ABSTRACT

Background: The crimping of stapes prosthesis to the long process of incus has always been the bugbear of an otologist. Malcrimping on one hand can lead to necrosis of the long process on the other hand it can lead to a residual air-bone gap or a postoperative reappearance of the conductive hearing loss. To solve these problems different types of stapes prostheses having different techniques to achieve a secure attachment to incus have been devised. *Methods:* The Titanium soft clip stapes Piston (Kurz) was used in 20 patients of otosclerosis undergoing stapedotomy and the results were analysed. This new type of stapes piston is a modification of the earlier àWengen clip piston (Kurz) which was designed to avoid the crimping onto the incus in stapedotomy. *Results:* Hearing results were analyzed using American Academy of Otolaryngology-Head and Neck Surgery guidelines including 4 frequency pure tone average. The mean postoperative air-bone gap was with in 10 db in 8 (40% of cases), up to 15 db in another 8 (40%) cases and in rest 4 (20%) was with in 20 db. No adverse reactions occurred during follow-up. *Conclusions:* The use of the titanium soft clip stapes piston gives good results in cases of stapedotomy for otosclerosis. The soft clip design is a new development in the evolution of stapes piston prostheses. Surgical introduction, placement, and fixation is easier than the earlier àWengen design of clip piston.

P-13 Biomechanics of the new generation of stapesplasty pistons: efficiency of the self crimped incudo-prosthesis junction

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ABSTRACT

Background: Fixation of prostheses to the long process of the incus is a key determinate of early hearing results and long-term outcomes in otosclerosis surgery. The Kurz CliP® àWengen, the Kurz Soft CliP® and the Gyrus SMart™ stapesplasty pistons have been designed to avoid the variability of manual crimping and achieve improved biomechanical performance. *Methods:* Six fresh cadaver temporal bones and laser Doppler velocimetry (LDV) was used to compare ease of piston placement and immediate sound transfer function. Each prosthesis was placed via an extended posterior tympanotomy through a fixed stapes foot plate (0.8mm stapedotomy). The test pistons included: Kurz àWengen CliP® and Soft CliP® (0.4mm & 0.6mm), SMart™ (0.4mm, 0.5mm, 0.6mm), Fisch (0.4mm), and Schuknecht (0.6mm). The nitinol prostheses were heat activated with diathermy. After placement of the prosthesis the sound transfer efficiency at the incus-prosthesis junction was assessed by comparing the relative velocities and phase of reflectors on the incus and prosthesis shoulder. Calibrated pure tone stimuli (closed field) were delivered at 97dB SPL from 0.1 to 10 kHz. All results considered were recorded at >10dB SNR. *Results:* The àWengen CliP®, Soft CliP®, and SMart™ pistons showed losses of <5dB at the test sound intensity with consistent phase across the prosthesis-incus junction. Some variability was seen above 4 kHz without clear trend. The three newer piston designs could be removed and replaced without impairing their fixation. The older pistons were difficult to crimp via the posterior tympanotomy and the results were more variable with repeated placement. Calculated volume velocity for the test pistons indicated a 5dB increased drive to the inner ear for the 0.6mm pistons versus 0.4mm (across all test frequencies). *Conclusions:* The àWengen CliP®, Soft CliP®, and SMart™ stapedotomy prostheses achieve an efficient sound couple to the incus. Our results appear to correlate well with the emerging clinical literature regarding the advantages of these pistons. *Funding Source:* Guy's Hospital Charitable Foundation Trust. Pistons donated by the manufacturers.

P-14 Measurements of Conductive Hearing Loss in Mice*

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ABSTRACT

Hypothesis: Our aim is to test a simple procedure for separating the conductive and sensorineural component of hearing loss based on non-invasive testing. *Background:* Measurement of Distortion Product OtoAcoustic Emissions (DPOAE) is a widely used technique for newborn hearing screening, due to its objectivity and noninvasiveness; while auditory brainstem response (ABR) is considered as an essential clinical method for evaluating hearing loss in infants. Both DPOAE and ABR are affected by the transfer function of the middle ear. However, individual measurements of either DPOAE or ABR thresholds can not separate middle-ear disorders, such as conductive hearing loss caused by amniotic fluid or Eustachian tube dysfunctions, from sensorineural hearing loss due to prenatal or postnatal factors. *Materials and Methods:* We wish to determine the differential effect of induced conductive pathology on DPOAE and ABR thresholds in mice, in order to quantify how the bi-directional passage of DPOAEs through the middle ear increases DPOAE threshold changes relative to ABR threshold changes. The conductive manipulations we perform include: perforations of the tympanic membrane, the induction of different fluid levels into the middle ear, ossicular fixations and ossicular interruption. We will also use laser-Doppler vibrometry to assess the effect of these manipulations on sound-induced middle-ear velocities. *Results:* Our preliminary results suggest that at frequencies below 10kHz in mice conductive hearing loss produces a doubling of the dB loss in DPOAE relative to ABR thresholds, with smaller effects at higher frequencies. *Conclusion:* The results of this study will be useful in the general assessment of conductive hearing loss in the clinic, as well as in the determination of hearing phenotype in mice with genetic hearing disorders. *Funding Source:* NIDCD.

P-15 A New Third Window Method for Middle Ear Measurements in a Human Temporal Bone Model

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ABSTRACT

Hypothesis: The “third window” method uses a small window in the basal turn of the cochlea to measure displacement with a laser Doppler vibrometer and compare prostheses, either active or passive, that stimulate the RW or the FP. It is hypothesized that this is a more suitable approach than previous approaches. *Background:* While cochlear sound pressure measurements are a solution to evaluate middle ear prostheses in human cadaver temporal bones, it is a technically challenging approach. A convenient, accurate and reproducible method is needed. *Methods:* A 1.5 mm TW is made into the scala tympani of the basal turn of the cadaver cochlea while keeping the endosteum intact to prevent loss of fluid. Reflective tape was placed on the TW to allow a Polytec HLV-1000 laser Doppler vibrometer to measure velocity in response to either sound pressure at the tympanic membrane or activation of a FMT (V-PORP, V-TORP, FMT-RW). The FP was measured in response to sound stimulation before and after the TW. *Results:* Below 1 kHz, there is no effect of the third window on the stapes footplate velocity, while above 1 kHz, differences of up to 10 dB are observed. The third window velocity can be higher than the footplate velocity by as much as 30 dB in the 1 to 5 kHz range. In the 0.8-5 kHz range, the V-TORP and V-PORP have an effective output of about 100-120 dB SPL and typically have a higher output by about 15 dB than the FMT-RW. *Conclusion:* The TW approach is a relative measurement, good for comparison purposes, but not an absolute measurement such as FP displacement or vestibular sound pressure measurements.

P-16 Different Kinds of Collagens in Tympanic Membranes

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ABSTRACT

Hypothesis: Inflammation of the tympanic membrane results in a change in collagen type distribution that lead to a tympanic membrane less resistant to the mechanical forces it is subjected to. *Background:* The load-bearing layer of the tympanic membrane is the lamina propria that consists of collagen. Different collagen types have specific properties regarding resistance to forces. The objective of the study was to investigate the distribution of different collagen types in healthy tympanic membranes. The results will serve as reference in forthcoming studies on tympanic membranes that have been subjected to inflammation. *Materials and Methods:* Immunohistochemical analysis of collagen type I, II, III and IV in healthy tympanic membranes from rats and humans. *Results:* In the pars tensa, collagen type II was found to the highest extent, but there was also presence of collagen type III. This was more obvious in the human tympanic membranes where it was possible to differentiate between the two collagen layers. Collagen type III was found to be strikingly more concentrated to the inner, circular collagen fiber layer. The fibrous annulus could immunohistochemically be subdivided into two portions. Collagen type II was the main collagen of the inner portion. The outer portion consisted predominantly of collagen type III. Collagen type IV was found in the basal laminae. *Conclusions:* Collagen type II was found to be the most abundant collagen in the lamina propria. There was also a marked presence of collagen type III in humans, especially in the inner, circular layer of the lamina propria where the relative distribution between the two collagen types showed a higher presence of collagen type III. The outer portion of the fibrous annulus had collagen type III as its major collagen constituent while the inner portion is mainly made up of collagen type II. *Funding Source:* Centre for Clinical Research, Västerås Central Hospital.

P-17 Middle-ear Power Analysis in Patients with Conductive Hearing Loss

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ABSTRACT

Hypothesis: A wide-band power analysis of middle-ear function will provide greater diagnostic information about middle-ear function than 226-Hz tympanometry in adult patients. *Background:* Wide-band measures of middle ear power reflectance and absorption

have recently been shown to be a better predictor of the presence of a conductive hearing loss and hold potentially greater diagnostic information than traditional 226-Hz tympanometry (Piskorski et al. 1999; JASA; Feeney et al. 2003, JSLHR; Allen et al. 2005. J Rehab Res Dev). More data are needed from patients with a variety of middle-ear disorders to further examine the diagnostic potential of wideband power analysis. *Materials and Methods:* The present study used a commercially available wideband acoustic impedance and reflectance system (Mimosa Acoustics, HearID) to evaluate 45 adult patients seen for an otologic evaluation for hearing loss. Following audiometry and 226 Hz tympanometry, each patient had a wideband middle ear analysis and distortion product otoacoustic emission test at ambient pressure using the HearID system. Reflectance results were compared to data from 30 adults with normal hearing. *Results:* Patients with similar middle-ear disorders had similar patterns of abnormal energy reflectance. Data analyses include establishing which frequency regions are most sensitive to differences between normal and abnormal ears. Abnormal reflectance was found in cases which exhibited normal 226 Hz tympanometry, suggesting higher sensitivity to middle-ear disorders. Individual case studies will be presented. *Conclusions:* The results suggest that wide-band power reflectance measures are more sensitive to middle-ear disorders than traditional tympanometry, and provide information that enhances the traditional middle-ear evaluation across the frequency region important for speech perception. *Funding Source:* NIH NIDCD.

P-18 Developing a non-surgical direct drive hearing device with an opto-electromagnetic actuator attached to the tympanic membrane: preliminary report*

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ABSTRACT

Hypothesis: sound signals can be transmitted and amplified via visible light between an optic probe and an actuator on the tympanic membrane. *Background:* a new type of non-surgical direct drive hearing aid system with an opto-electromagnetic actuator attached onto the ear drum was designed, fabricated and tested. *Materials and Methods:* A finite element middle ear model was used to estimate the optimal electromagnetic force and to predict the frequency-amplitude characteristics of the actuator. Additionally, the optimal air gap between the magnet and coil, input current, and vibration force were calculated by this model. The actuator was fabricated based on the estimation and its vibration characteristics were measured using a Laser Doppler Vibrometer on a formalin-fixed temporal bone. *Results:* The actuator consisted of two photodiodes, two permanent magnets, an aluminum ring,

two opposing wound coils, a latex membrane and a Provil Novo™ membrane. Results indicated that the actuator can provide an electromagnetic force of 15dyn under conditions including 500 turns of each coil, a 0.2 mm air gap, and a current of 164 μ A. Finally, the actuator showed displacements of vibration between 30 nm to 1nm from 300 Hz to 6500 Hz, which reduced in amplitude at higher frequencies. The average gain of the actuator with 140 μ A on the umbo displacement was about 20 dB relative to 87 dBA at the distance of 6 cm from the tympanic membrane and 0 μ A in actuator. Conclusion: sound signals can be transmitted remotely via the visible light by way of the novel opt-electromagnetic actuator with some gain and limited distortion. *Funding Sources:* This work was supported by a grant from the National Taiwan University Hospital (NTUH 96 A01), and a grant from the National Science Council of Taiwan (NSC 95-2815-C-002-043-E).

P-19 A Self-adjusting Ossicular Replacement Prosthesis

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ABSTRACT

Hypothesis: An ossicular replacement prosthesis (ORP) with adjustable length is an attractive proposition as it would avoid the need to use a device with an exact fit and could reduce inventory substantially. It is believed that an ORP containing an appropriately designed damping element could achieve this feature, but the device must be capable of efficient vibration transmission. *Background:* The concept of a self-adjusting ORP is not new. Several mechanical concepts have been put forward but only a few have actually been produced. Most of these devices contain a spring element as they are simpler to manufacture than damping or other elements. With a spring, there is a compromise to be made between ensuring that it is stiff enough to transmit sound without resonance, while also giving it sufficient flexibility to be adjustable. Two approaches were made to create a self-adjusting ORP, the design criteria being ease of adjustability during surgery, compliance under changes in atmospheric pressure and minimal attenuation in vibration transmission. Both were based on fluid devices. *Materials and Methods:* The first design used a dilatant fluid, which becomes stiffer as its shear rate increases, so it could be expected to stiffen more at audio frequencies than at the lower frequencies of ambient pressure change. The second used a damping element in the form of a dashpot. The testing process required the construction of a miniature materials testing machine, comprising a piezoelectric vibrating platform and a force sensor to measure impedance, and a laser vibrometer to measure output displacement. The supporting structure was very rigid so that nanometers of movement could be measured accurately. *Results:* A range of dilatant fluids were tried but their performance was not good enough to satisfy all the criteria above. A cylindrical damping element in combination with a suitable viscosity performed well using a range of piston configurations. In a temporal bone experiment, in which one end of the damper

was attached to the malleus and the other end to the stapes, the stapes footplate movement from 0.25-10 KHz of the prototype ORP performed nearly identically to a plastic ORP tested in the same bone. *Conclusions:* A simple damping element could function well in a self-adjusting ORP. Further experimentation is required to test the system in more temporal bones. *Funding Source:* The project was funded by Scottish Enterprise, Glasgow, UK.

P-20 Stapes Model: Two-layer annular ligament

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ABSTRACT

Hypothesis: Histology indicates that the annular ligament has a sandwich-like cross-section, with collagen fibers concentrated near the medial and lateral surfaces, but relatively sparse in between. We hypothesize that this construction may be suited for attenuating sound to the cochlea when the stapes muscle is activated, and for attenuating high static pressures so as to avoid damaging the cochlea. *Background:* The stapes annular ligament plays a critical role in determining stapes motion, and has traditionally been modeled as a thick single layer with collagen fibers distributed throughout its volume. This is inconsistent with histological observations, however. *Materials and Methods:* The two fiber layers are considered as ring-shaped plates, each divided into 200 sub-elements that are analyzed as tapered and clamped-guided Euler-Timoshenko beams. Essential features of the model are the width, overall thickness, and angle of inclination of the fiber layers around the annular ligament. The inertial properties of the rigid stapes and the geometric data of the annular ligament are calculated from 3-D reconstructions obtained from μ CT imaging. *Results:* The variation in geometry produces full stapes-motion-to-fluid-coupling with six degrees of freedom in the stiffness matrix. A reasonable volume fraction of fibers produces stiffness with force in the axial force (FZ) direction consistent with the values measured and used in several laboratories. *Conclusions:* The physiologically-based model using Euler-Timoshenko beam theory for the annular ligament yields a stiffness matrix that couples the effects of force and moment components. Although only linear analysis is currently presented, such coupling could play a significant role in the modeled behavior of the ossicular chain through the entire frequency range when nonlinear effects due to tension in the stapedius muscle are introduced. [Work supported by Grant No. DC 05960 from the NIDCD of the NIH.]

P-21 The extended iPiston in stapedotomy: First clinical results

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ABSTRACT

Incus movement acts as a lever with a rotational axis at the short process. Conventional fixation of most stapes prostheses attach at the long process of the incus short of the lenticular process with a rectangular approach to the stapes footplate. In theory peak-to-peak displacements increase with the length of the lever. We have developed the extended stapes prosthesis “iPiston”: attachment at the usual place on the long process, wire extension towards the promontory and posteriorly, angulation with a ball-joint. Lab measurements with Laser Doppler supported an improved amplitude. We now present our first clinical results from stapedotomy patients. At the time of this abstract our results are not all ready. A conclusion is not yet possible. By June 2009 we will have collected this data.

P-22 Feasibility study of Round Window Stimulation with the MET-V Implantable Middle Ear Device: a Temporal Bone Study

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ABSTRACT

Background: The MET-VTM middle ear implant (MEI) can drive the round window (METRW) from a stable bracket mount. The surgical approach requires planning to optimize RW visualization, loading and fascia placement. Mechanics data guides potential candidate selection i.e. achievable peak equivalent sound pressures (LE_{max}). *Materials and Methods:* Six fresh cadaver temporal bones were prepared with transfacial and transjugular approaches to the RW. Exposure was optimized by skeletonization of the chorda-facial nerve junction and niche saucerization. METRW drive angle, with extended 0.5 and 1mm ball attachments, was laser assessed. In a sound proof booth, calibrated sinusoidal stimuli (0.25-14kHz) drove either a TDTCF speaker, via foam insert (80-100dB SPL), or MET (1VRMS_{Max}). A B&K microphone recorded TM surface sound pressures. Stapes, RW, and ball velocities were recorded by LDV. RW loading was assessed by graded deflection, calibrated micro-adjustment, and transducer inductance changes. *Results:* The probe tip to mid RW angle ranged 15°-30°. Effective RW loading was achieved with 0.5 mm and 1mm ball tips, resulting in RW deflection, reduced impedance but without inductance change. Side-loading was possible by collar screw adjustment. Five temporal bones had ‘normal’ stapes

transfer functions (HTV) and cochlear hydration (intact RW reflex, normal RW transfer function (HTV-RW \approx 1mm/s/Pa) and RW-stapes phase-lag (\approx 0.5cycle). Stapes velocities changed linearly with RW ball velocity. The mean LEMax for METRW drive at 1VRMS was 106 dB SPL for facial recess and 108 dB SPL for transjugular approaches. Temporalis fascia improved LEMax by 2-4dB - a frequency dependant effect. The comparison mean LEMax for MET driven incus was 126dB SPL. The peak recorded sound pressure (reverse transfer function) for METRW drive was 114dB SPL. Measured harmonic distortion was -26dB at 1kHz. *Conclusions:* Resultant stapes velocities from MET-VRW stimulation indicate that significant levels of mechanical cochlear stimulation are achievable. Advantages of bone mounting, fine adjustment, low distortion levels, and broad-band frequency response warrant clinical assessment. *Funding Source:* Otologies Education Grant.

P-23 Cochlear responsiveness to frequency-independent constant-velocity direct mechanical stimulation of the round window (RW) with the MET-V transducer

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ABSTRACT

Introduction: Little objective physiological data is available for electromechanical stimulation of the cochlea via the round window (RW). Aim: To examine whether cochlear responses to direct RW stimulation by the Otologies MET-VTM (MET) transducer is linear and frequency independent and solely determined by the physical drive applied. *Methods:* Nine chinchillas were anaesthetized following the UCHSC animal welfare guidelines. KTP laser was used for ossicular chain exposure and tensor tympani tendon division. A silver wire electrode at the RW recorded CM and CAP. The MET with 0.5mm ball-tip was loaded onto the malleus handle (90°) or RW (~70°) with micromanipulator. Calibrated sinusoidal stimuli (0.25-14kHz) were delivered via TDTCF speaker and insert ear-piece (16-50dB SPL) or MET (0.2-56mVRMS). Malleus, stapes, RW, and ball velocities were recorded by LDV (SNR >6dB). The RW load achieved by calibrated micro-adjustments resulted in a moderate graded deflection of the RW. *Results:* The stapes velocities for MET RW drive or MET malleus drive demonstrated maxima at 2-3 kHz - consistent with MET resonance. The stapes velocity was proportional to measured MET ball velocity at all frequencies. Malleus stimulation produced significantly higher stapes velocities than RW stimulation by 20-40dB - with proportionately lower CM thresholds. CM thresholds ranged from 16-50 dB SPL for acoustic and 0.2-56 mV for RW MET stimulation (frequency dependent). The relationship of the CM threshold for acoustic (dB SPL) and MET RW

drive (dB mV) suggested an increased sensitivity to RW stimulation above 1000Hz. When MET RW drive thresholds were normalized for stapes velocity they decreased by ~10 dB above 1 kHz (unlike the flat thresholds for acoustic and MET malleus drive). This finding was confirmed by the ball-tip velocity being held constant at each frequency by applying an FIR filter to the driving voltage. The FIR filter reduced ball velocity variation due to resonance from 70dB to just 10dB. The resultant CM thresholds still decreased by a mean 9dB in the 1-8kHz range (95% CI: 4.6 – 13.3, $P < 0.001$) and maximally by 15dB at 6kHz. *Conclusions:* The apparent sensitivity of the cochlear to high frequency RW drive is likely to be an important property for the treatment of mixed hearing-loss patients with the MET-VTM.

P-24 Making Sense of Oval and Round Window Volume Displacement Asymmetry in Bone Conduction: A Third Window near the Round Window?

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ABSTRACT

A three-dimensional structure-fluid coupled FE model of the human cochlea consisting of basilar membrane (BM), bony shell, oval window (OW), round window (RW), scala vestibuli (SV), scala tympani (ST), and scalae fluid is presented. In the FE model simulation, AC stimulation was simulated by the acceleration of the OW, and BC stimulation by the assumed rigid-body acceleration of the bony shell containing the scalae fluid. Simulated results by AC were in reasonable agreement with experimental data reported in the literature, including: best frequency (BF) map, BM motion, cochlear input impedance, and OW and RW volume displacement ratio. For BC, the BM motion and OW and RW volume displacements of FE results were compared with experimental data. The simulated BM motions were consistent with experimental measurements (Stenfelt et al., 2003). The magnitude of RW volume displacement is equal to that of the OW volume displacement, whereas the experimental results show significant difference in magnitude between the two above 200 Hz (Stenfelt et al., 2004). A stated hypothesis for this “asymmetry” in OW and RW volume displacements is the possibility of a third window in the cochlea. To test this hypothesis, we included a third window at different locations. Preliminary indications are that a third window reproduces the OW and RW asymmetry consistent with Stenfelt’s data, when it is in the RW vicinity. Work sponsored by the Air Force Office of Scientific Research (AFOSR) under a STTR grant (Contract NO: FA9550-06-C-0039).

P-25 A Comparison of the Non-linear Response of the Ear to Air and to Bone Conducted Sound

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ABSTRACT

Hypothesis: That the nonlinear response of the ear is similar for both air and bone conducted sound. *Background:* The nonlinear response of the ear to air-conducted sound has been studied to some depth. However, the nonlinear response of the ear to bone-conducted sound has received less attention. An innovative technique for comparing the nonlinear response of humans to air and bone conducted sound is presented. *Materials and Methods:* Two different human subject test techniques were used in this investigation. The first was a psychoacoustic investigation in which we measured the perceived cancelation of a bone-conducted sound stimulus with another bone-conducted sound stimulus and also with an air-conducted sound stimulus. The measurement was accomplished through a loudness-matching technique. The second investigation used Distortion Product OtoAcoustic Emissions (DPOAE) to make objective measurements of the response of the ear to both an air-conducted sound stimulus and a bone-conducted sound stimulus. The results were compared to determine whether the measured compression effects were similar for the different types of stimuli. *Results:* Our results show that both the measured psychoacoustic response and the measured objective response of the ear to air-conducted sound and to bone-conducted sound are similar. *Conclusions:* The same nonlinear compression mechanism is involved in the response of the ear to both air-conducted sound and to bone-conducted sound. *Funding Source:* Air Force Office of Scientific Research.

P-26 On the heating process of shape memory alloy prostheses

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ABSTRACT

Background: Self crimping pistons with wire loops made from shape memory alloy have to be heated up to fix them at the long process of incus. This may cause damages on the natural structure. *Hypothesis:* Heating the loop by means of laser, in the clinical practice is discussed what is the necessary power and duration of laser shots and how many shots should be given. During the heating process it is necessary to bring the metallic loop above the phase transformation temperature but an excessive heating of the mucosa and bone should be avoided. *Materials and Methods:* To simulate the thermal behavior of the prosthesis and the thermal input of the laser, a finite element model was developed which

allows the investigation of the heat input and its distribution. Various sequences of laser shots were considered and studied, different design variants of loops concerning their shape were compared. The heating process is demonstrated by means of video animations. *Results:* The heat distribution by conduction, transfer and radiation depends strongly on the shape of the loop. Water drops around the laser input area serve as buffers and change the heat flux. It is shown that the intensity and duration of laser shots as well as the time history of the shot sequence (number of shots and time in between) can be optimized in order to reach the phase transformation temperature, to get a complete phase transition in the loop and to prevent the surrounding structures from overheating.

P-27 Measurement of Nonlinear TM response by Scanning LDV*

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ABSTRACT

Three human temporal bones with intact tympanic membranes (TMs) and mobile ossicular chains were stimulated acoustically while the out-of-plane movement of the TM was measured using a scanning laser Doppler vibrometer (SLDV). The external auditory canal was sealed acoustically by means of a silica window with normal of 99.9% transmission at the 633 nm wavelength, allowing measurement of the dynamic response at each location on a grid covering the TM, thus images of the TM deflected shape at different frequencies are obtained. Response was measured over the range of frequencies from 100 Hz to 8 kHz. All three temporal bones were stimulated at 94 dB SPL, and one specimen was also stimulated at 135 dB SPL. At 94 dB SPL, TM deflection was greatest in all three specimens at frequencies just below 3 kHz, with broad local maxima anterior and posterior to the manubrium of the malleus. At 135 dB SPL, deflection was greatest at lower frequencies, with a more complex pattern of local maxima. At 1400 Hz, peak local velocities ranged from 5 to 20 micrometers/sec. at 94 dB SPL, and 200 to 500 micrometers/sec. at 135 dB SPL, a response lower than would have resulted from a linear increase with sound pressure. The asymmetric pattern of deflection and nonlinear response to increasing sound pressure levels may result from a varying mechanism of response in the TM and middle ear. The experimental technique used here may be combined with SLDV imaging of the ossicles to develop a simultaneous view of TM deflection and ossicular movement. Observations of TM nonlinearity at extremely high SPL have significance in the modeling of acoustic trauma.

P-28 Does Silastic Sheeting Over the Round Window Niche Affect Sound Transmission in the Human Middle Ear?

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ABSTRACT

Background: Silastic sheeting is commonly used in middle ear surgery to prevent the formation of adhesions between the tympanic membrane and the medial bony wall of the middle ear cavity. This sheeting is often placed, advertently or inadvertently, so as to cover the round window niche. The question of whether or not the silastic sheeting inserted during middle ear surgery affects hearing in any way is very difficult to answer from clinical data and studies. This is due to the many confounding factors that may have a detrimental effect on hearing in the chronically inflamed ear. In addition, the resolution of clinical audiograms is very poor. The effects of surgically shielding the round window niche in the presence of an intact tympanic membrane and ossicular chain have thus not to date been satisfactorily studied. *Objectives:* To investigate the effect of acoustically shielding the round window with 1mm thick silastic sheeting on middle ear sound transmission in otherwise intact human temporal bones. *Methods:* Using a fresh human cadaveric temporal model, a computerized Laser Doppler Vibrometry system is used to measure vibrations at the umbo and on the stapes footplate in response to sound introduced into the middle ear. Stapes displacement is used as a measure of hearing level. The measurements are repeated after shielding the round window using a 1mm thick silastic sheet. The experiment was performed on 5 fresh temporal bones. *Results:* We found that shielding the round window with silastic produced no significant difference in the measurements at stapes footplate. At the umbo, a slight drop at 250 Hz was measured after shielding. *Conclusion:* In the presence of intact tympanic membrane and ossicular chain, shielding the round window with silastic sheeting has no clinically significant affect on sound transmission by the human middle ear.

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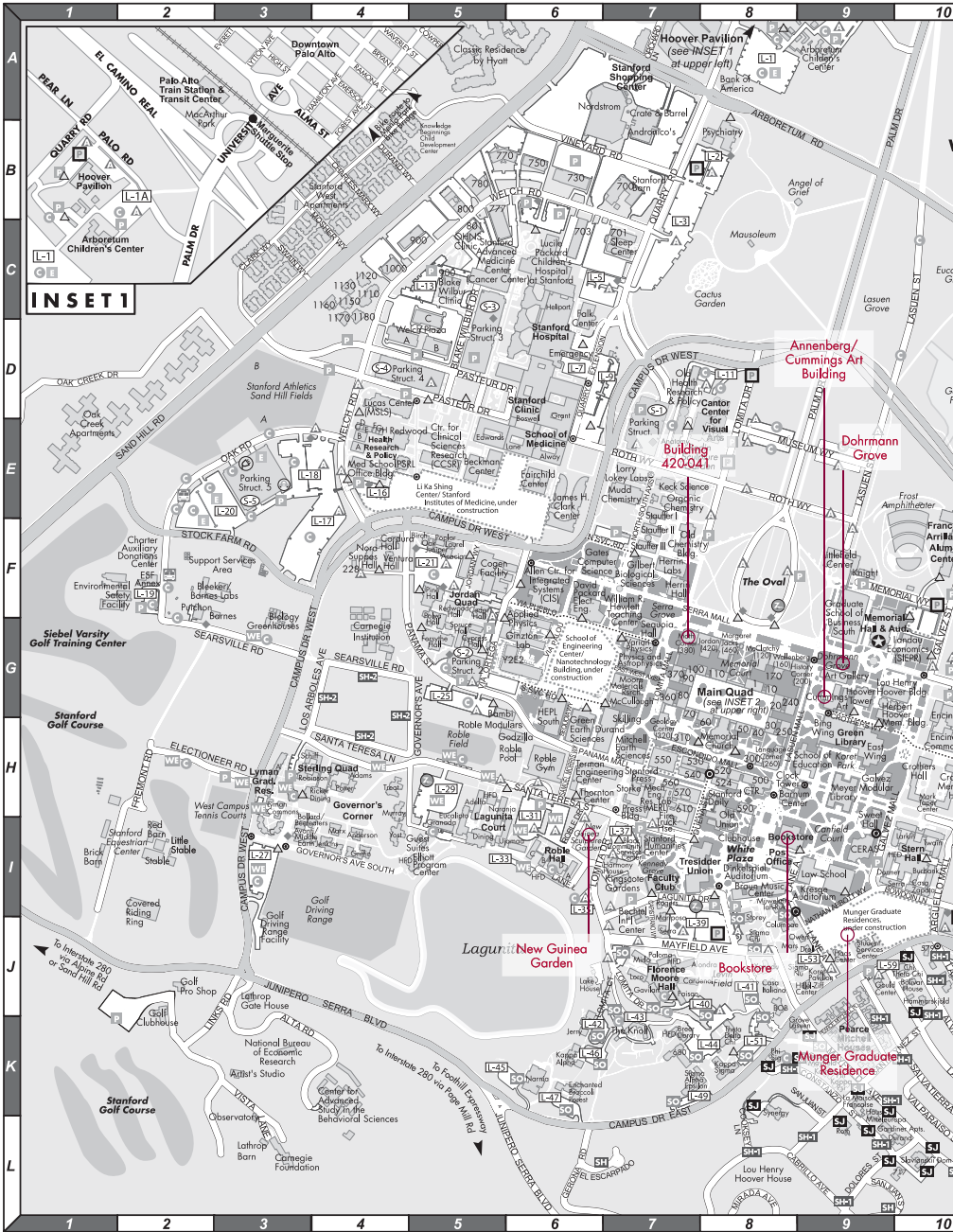
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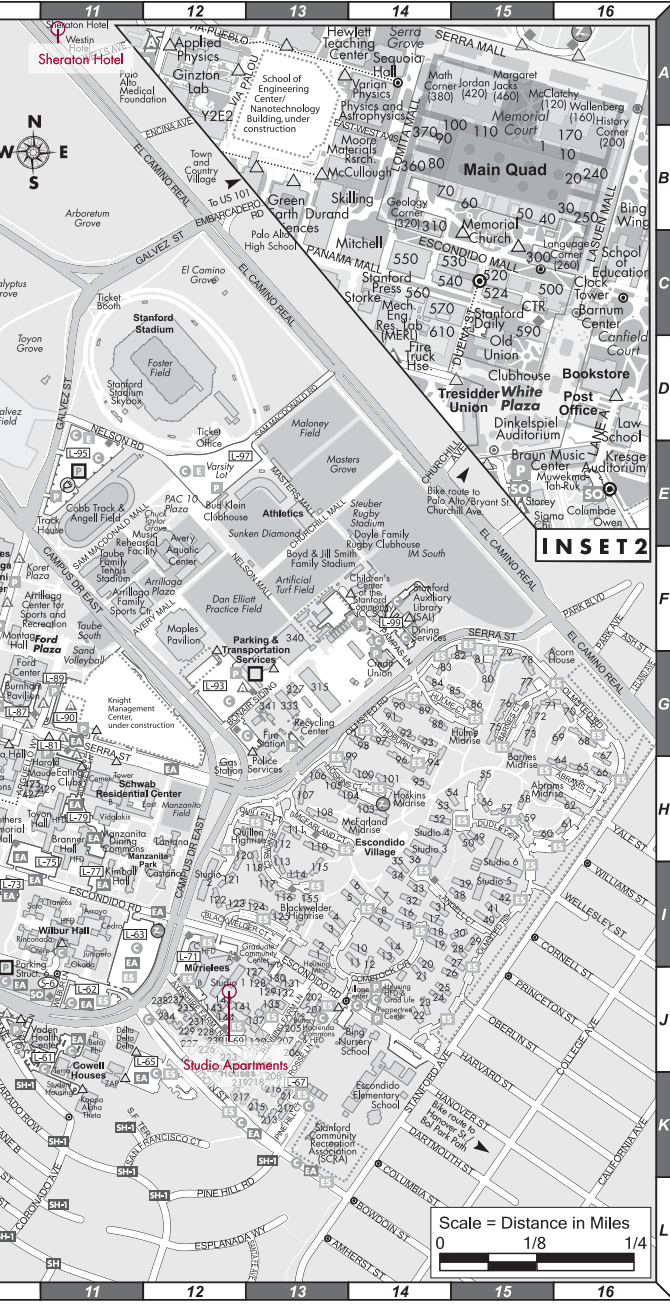
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