Lecture 12. Middle Ear Structure-Function & Pathology

I. The Middle ear

A. Anatomy of the Middle Ear

Figure 12.1 A schematic 'coronal'-section of the human auditory periphery

Image removed due to copyright considerations.

Source: Anne Green drawing in Kiang NYS, Peake WT. "Physics and Physiology of Hearing." In *Stevens' Handbook of Experimental Psychology.* Edited by Atkinson R. C., Herrnstein R. J., Lindzey G., and Luce R. D. New York: John Wiley & Sons, 1988.

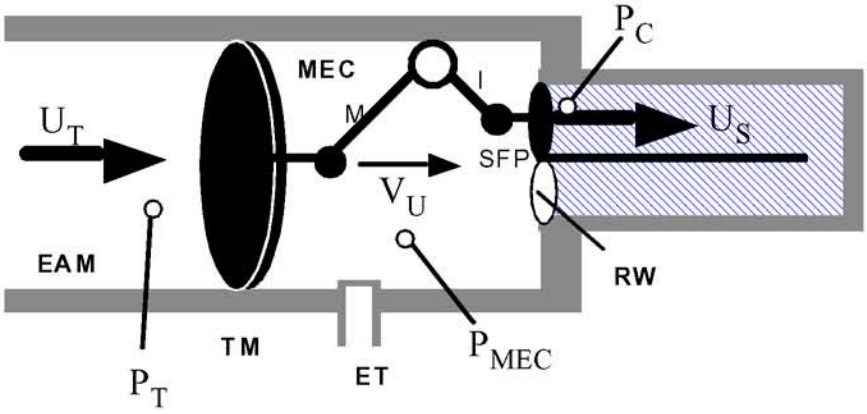
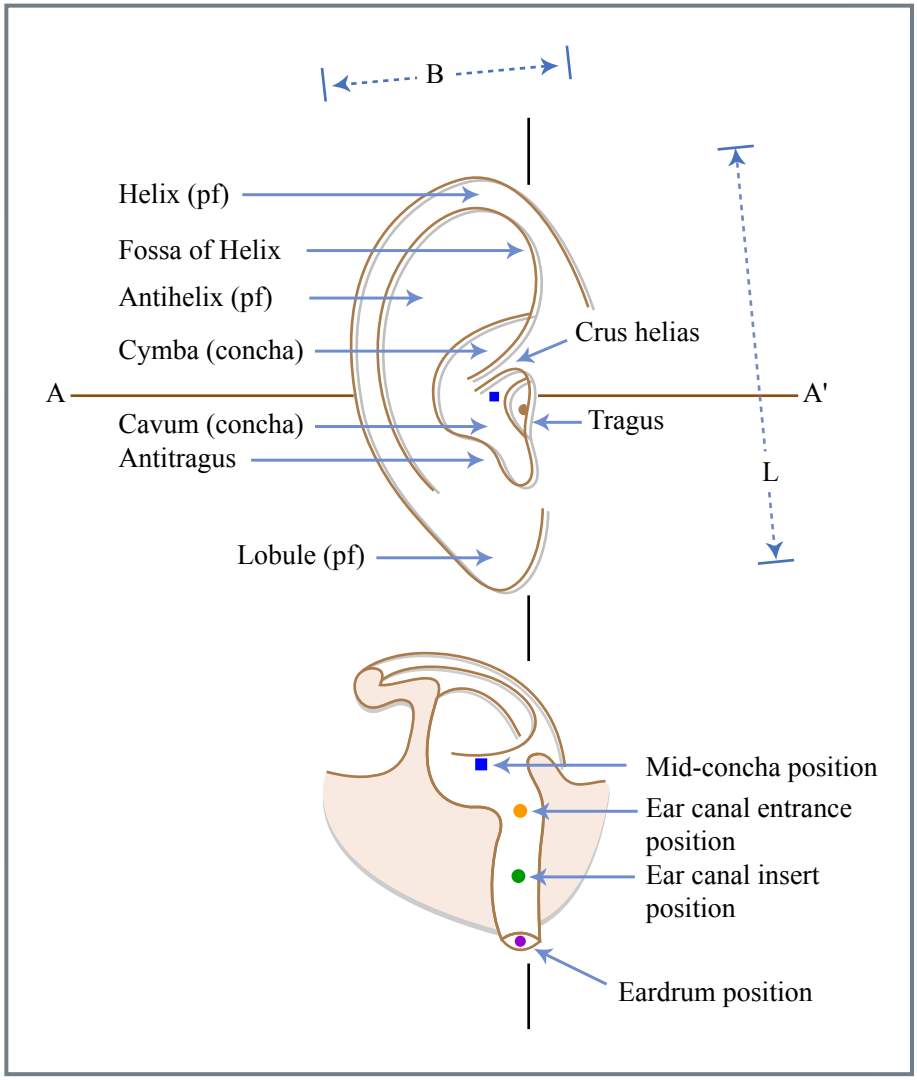


Figure 12.1a: Mechano-Acoustic Analog of the Middle Ear

Adapted from

12.2a The external ear of humans (from Shaw EAG. The external ear. In: W.D.Keidel, W.D.Neff, ed. *Handbook of Sensory Physiology: Vol V/1: Auditory System.* New York, Springer-Verlag. 1974;455-490.)



The cat external ear
(Rosowski JJ, Carney LH, Peake WT. (1988). The radiation impedance of the external ear of cat: Measurements and applications. Journal of the Acoustical Society of America 84:1695-1708.)

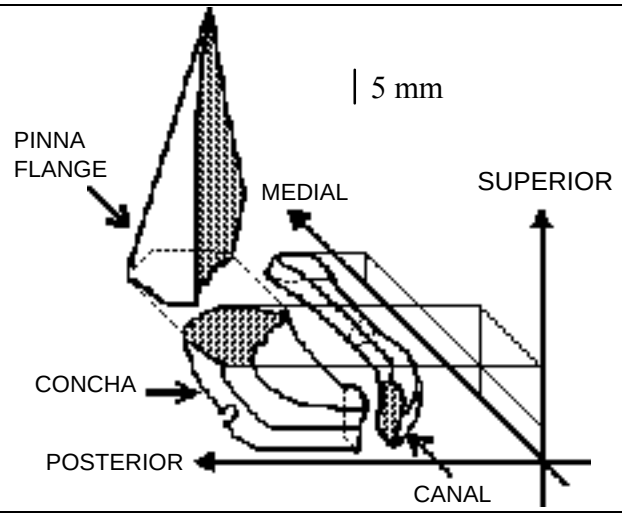


Figure 12.3 Two Views of the Human Tympanic membrane (the eardrum)

Image removed due to copyright considerations.

Source: Schuknecht, H. F. *Pathology of the ear*. Cambridge: Harvard University Press, 1974.

Figure 12.4 A Medial View of the Human Middle Ear

-TM
-ossicles
  Malleus with Umbo
  Incus
  Stapes with footplate
-middle-ear muscles
  Tensor Tympani)
  Stapedius Muscle
-mastoid air spaces
-Tympanic cavity
-Eustachian Tube
-VII (Facial) Nerve

Image removed due to copyright considerations.

Source: Henson, O. W. "Comparative anatomy of the middle ear." In *Handbook of Sensory Physiology: The Auditory System.* Edited by Kiedel W. D., Neff W. D. 1974, pp. 39-110.

Figure 12.5 The Three Human Ossicles

Image removed due to copyright considerations.

Source: Henson, O. W. "Comparative anatomy of the middle ear." In *Handbook of Sensory Physiology: The Auditory System*. Edited by Kiedel W. D., Neff W. D., 1974, pp. 39-110.

Figure 12.6: A cast of the Human Inner ear: After Schuchnect 1974

Image removed due to copyright considerations.

Source: Schuknecht, H. F. *Pathology of the ear*. Cambridge: Harvard University Press, 1974.

Figure 12.7: A horizontal section through the human ear:
Source: Schuknecht, H. F. *Pathology of the ear*. Cambridge: Harvard University Press. 1974.

Image removed due to copyright considerations.

B. There is a wide variation in the form and function of the ossicles and middle-ear air spaces.

Fig 12.8: (Source: Rosowski, J. J. *The Evolutionary Biology of Hearing.* New York: Springer-Verlag, 1992, pp. 625-631.)

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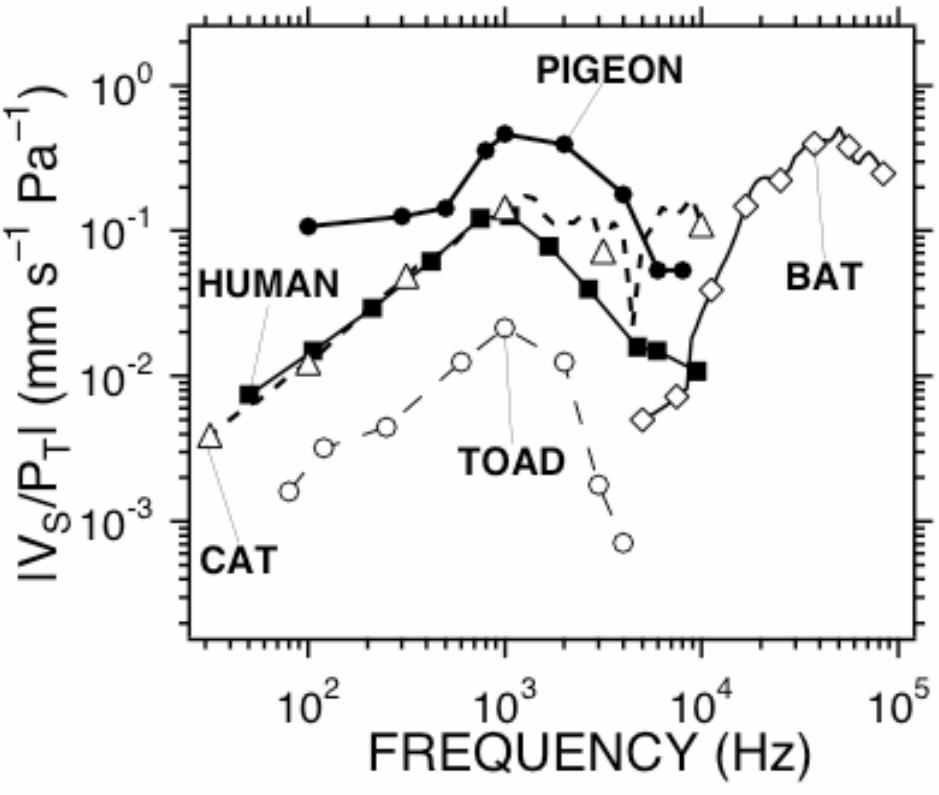
Figure 12.9

Image removed due to copyright considerations.

The middle ears of mammals are different from those of other terrestrial vertebrates in that other vertebrates (bird's reptiles and amphibians) have a single ossicle, a curved out tympanic membrane, one or no middle-ear muscle and a middle-ear cavity that is less well defined. (Source: Rosowski, J. J. "The middle and external ears of terrestrial vertebrates as mechanical and acoustic transducers." In *Sensors and Sensing in Biology and Engineering.* Edited by Barth, F. G., Humphrey J. A. C., and Secomb T. W. New York: Springer-Verlag, 2003, pp.59-69.)

Fig 12.10: Middle-Ear System Function: Stapes Velocity / Sound Pressure in Ear canal



Rosowski 2003

C. There is also a wide variation in the hearing range of different animals

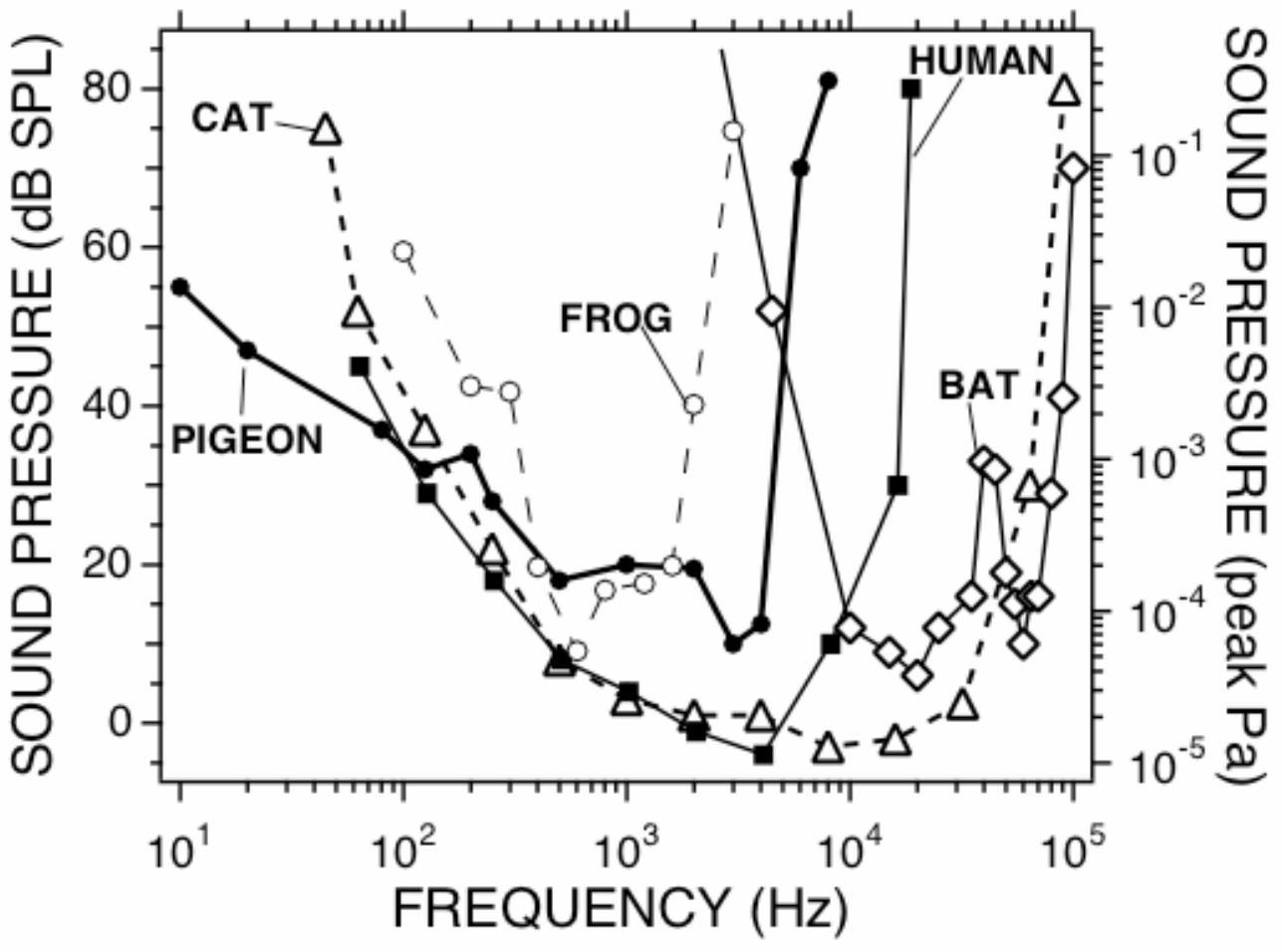


Figure 12.11:
Pure-Tone Audiograms (Threshold sound level vs frequency contours for the human (Sivian & White 1932) domestic cat (Heffner and Heffner 1985),bat (Long & Schnitzler 1975), pigeon (Heinz et al. 1985) and Bull Frog (Megela-Simmons 1987). The abscissa is tone frequency. The left ordinate is the threshold sound pressure in dB SPL. The right ordinate is the threshold in pascals. (Rosowski 2003)

D. The Effective Stimulus to the Inner Ear is a Difference in Sound Pressure at the Two Cochlear Windows

$$\underline{P}_{WD} = \underline{P}_S + (\underline{P}_{OW} - \underline{P}_{RW})$$

$\underline{P}_{WD}$ is the Effective sound pressure difference at the cochlear windows

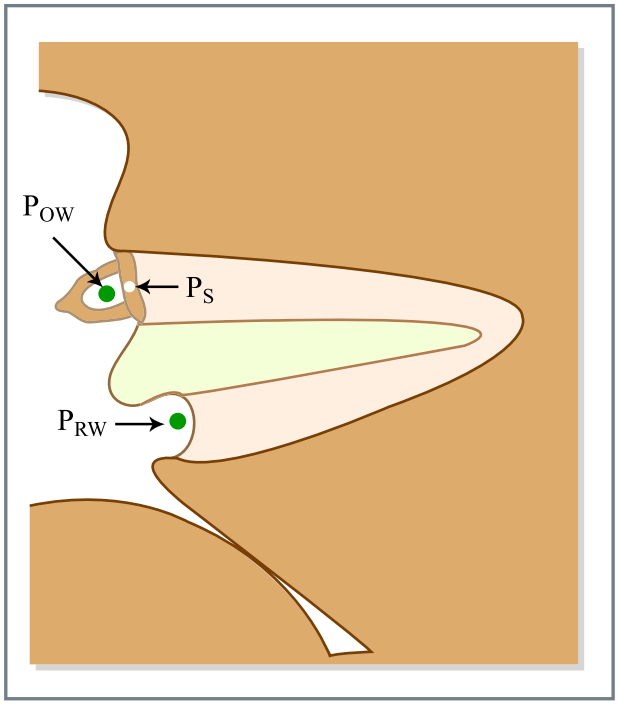
$\underline{P}_S$ is the effective sound pressure produced by motion of the ossicular chain

$\underline{P}_{OW}$ is he sound pressure in the middle-ear cavity outside of the oval window

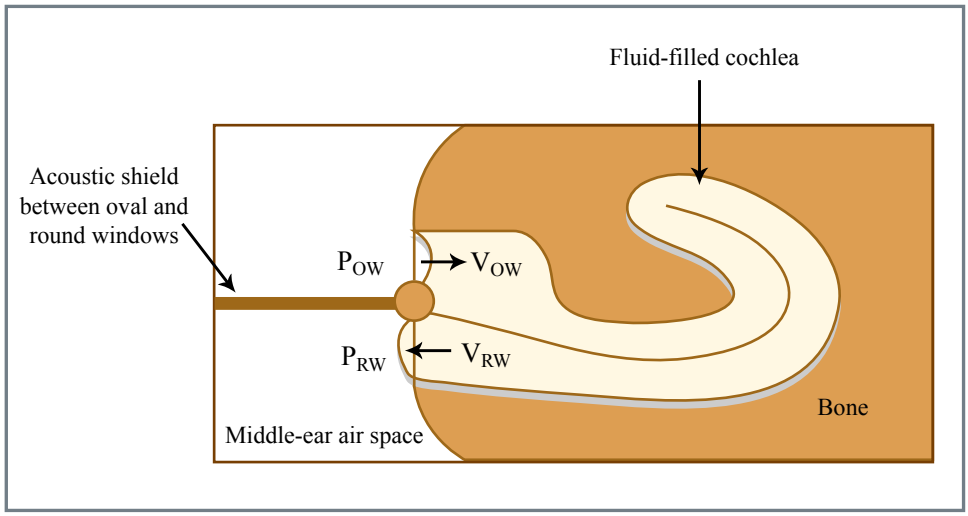
$\underline{P}_{RW}$ is the sound pressure in the middle ear cavity outside the round window

In the Normal Middle Ear:

$\underline{P}_S >> (\underline{P}_{OW} - \underline{P}_{RW}) = \Delta\underline{P}$



A Test of the pressure difference hypothesis (Voss et al 1995)



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Source: Merchant, S. N., and J. J. Rosowski. " Auditory Physiology (Middle-Ear Mechanics)." In *Surgery of the Ear.* 5th ed. Edited by A. J. Gulya, and M. E. Glasscock, III (Hamilton, Ontario, B. C. Decker, 2002) pp. 59-82.

Ossicularly Coupled Sound in the Normal Ear
$\underline{P}_{WD} \approx \underline{P}_S$
and
Acoustically Coupled Sound
$(\underline{P}_{OW} - \underline{P}_{RW}) = \Delta\underline{P}$

Image removed due to copyright considerations.

Source: Merchant, S. N., and J. J. Rosowski. "Auditory Physiology (Middle-Ear Mechanics)." In *Surgery of the Ear.* 5th ed. Edited by A. J. Gulya, and M. E. Glasscock, III (Hamilton, Ontario, B. C. Decker, 2002), pp. 59-82.

In Cases of Severe Ossicular Disruption Acoustic Coupling Limits the hearing loss : (Merchant & Rosowski 2002)

A: Interrupt I-S Joint **B: Lost TM, malleus & incus**

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Image removed due to copyright considerations

Source: Merchant, S. N., and J. J. Rosowski. "Auditory Physiology (Middle-Ear Mechanics)." In *Surgery of the Ear*. 5th ed. Edited by A. J. Gulya, and M. E. Glasscock, III (Hamilton, Ontario, BC Decker, 2002), pp. 59-82.

Type IV Tympanoplasty:
Use of Acoustic Shielding to Manipulate Acoustic Coupling by Increasing the Window Pressure Difference: Merchant SN and Rosowski JJ. 2002

Image removed due to copyright considerations.

Source: Merchant, S. N., and J. J. Rosowski. "Auditory Physiology (Middle-Ear Mechanics)." In *Surgery of the Ear.* 5th ed. Edited by A. J. Gulya, and M. E. Glasscock, III (Hamilton, Ontario, BC Decker, 2002), pp. 59-82. □□

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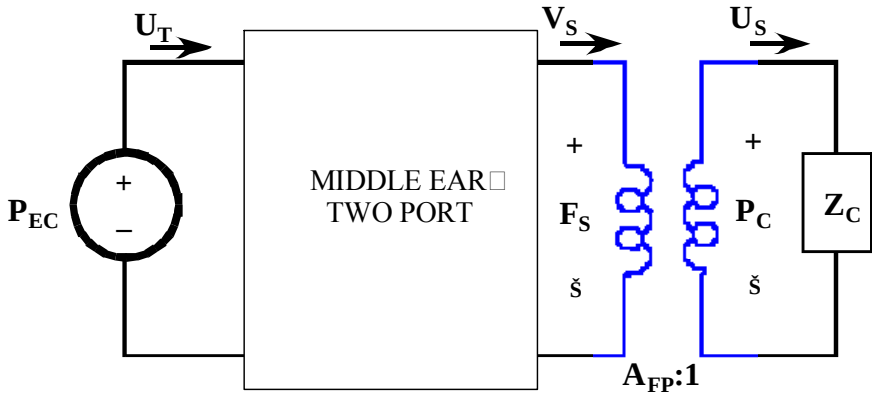
Source: Merchant, S. N., and J. J. Rosowski. "Auditory Physiology (Middle-Ear Mechanics)." In *Surgery of the Ear.* 5th ed. Edited by A. J. Gulya, and M. E. Glasscock, III (Hamilton, Ontario, BC Decker, 2002), pp. 59-82. □□

E. Another reconstructive surgery; the stapedectomy

Image removed due to copyright considerations.

Source: Rosowski, J. J., and S. N. Merchant. "Mechanical and Acoustic Analysis of Middle Ear Reconstruction." *American Journal of Otology* 16 (1995): 486-497.



P_{EC} = Ear Canal Sound Pressure
U_T = TM Volume Velocity
F_S = Force on Stapes/Prosthesis
V_S = Stapes/Prostehesis Velocity
A_{FP} = Area of the Footplate/Prosthesis
P_C = Sound Pressure in the Cochlea
U_S = Stapes/Prosthesis Volume Velocity

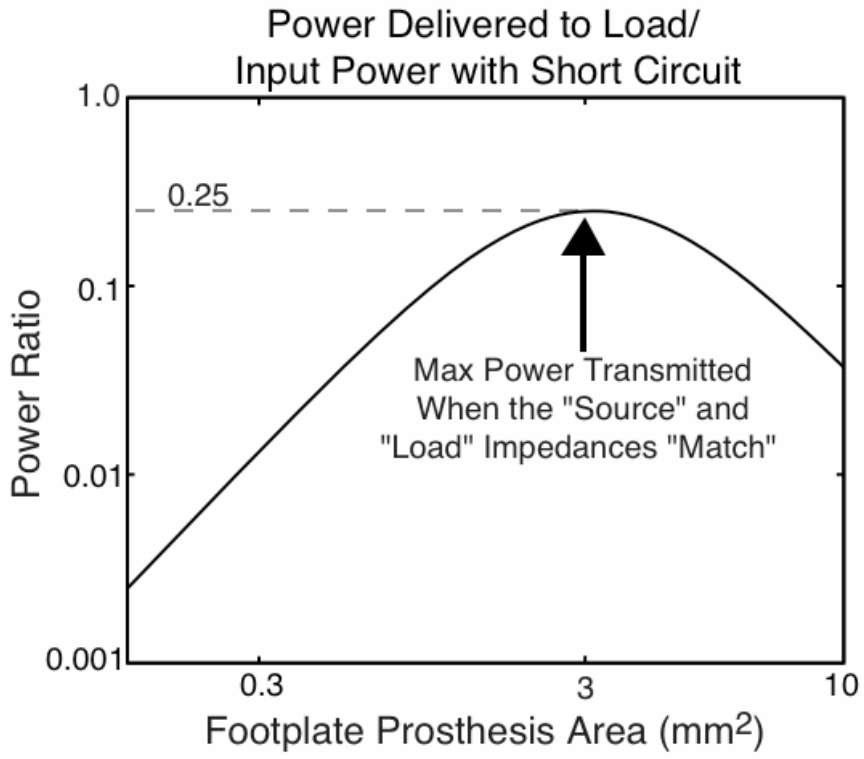
	$\mathbf{Z_C}$ = Cochlear Acoustic input Impedance

Predicted Variations in Hearing Level with Different Prosthesis Cross-Sectional Areas

Image removed due to copyright considerations.

Source: Rosowski, J. J., and S. N. Merchant. "Mechanical and Acoustic Analysis of Middle Ear Reconstruction." *American Journal of Otology* 16 (1995): 486-497.

Rosowski & Merchant 1995



If we define the *Source Impedance* as the impedance on the Left (input side) of the transformer when the source is turned off, and the *Load Impedance* as the impedance loading the Right (output side) of the transformer, then the *Maximum Available Power* reaches the load when the transformer *matches* the two impedances. Matching occurs when the two impedances are complex conjugates.