Concluding remarks and future perspectives in regard to imaging
Concluding Remarks

The remarkable progress of cochlear implants over the last decades has widely broadened their application. This put higher demands to all people involved in the selection, treatment and rehabilitation of cochlear implant candidates. Just like the development of implants resulted from interplay between physicists and surgeons, scientists and health care providers, the further directions in cochlear implant research and patient care need to be driven by multidisciplinary insights/groups. To enable and encourage such interdisciplinary cooperation a common ground for clear and easy exchange of findings in scientific and clinical studies is mandatory. Consensus meetings and thoughtful deliberations with representatives from different fields helped to crystallize such a common cochlear framework, which was presented in this thesis.

Radiologists may contribute to these further developments as well as to individualized patient care. This thesis focused on the potential of multisection computer tomography for detailed in vivo assessment of both the postoperative condition and preoperative cochlear morphology. The choice for this widely available imaging tool will hopefully enhance the awareness amongst radiologist about their role in the evaluation of cochlear implantees. It bears the possibility to open the door to multicenter studies on large patient groups. However as shown in this thesis current scanners have still shortcomings regarding cochlear imaging. Although scanner resolution has amazingly increased with the last generation CTs, mainstream of medical imaging exploits new technical developments for scanning faster and larger volumes, rather than visualizing small structures in greater detail. To accurately investigate cochlear trauma or to visualize cochlear implants with small electrode contacts and narrow inter-contact distances improved scanner resolution or other imaging techniques will be required. Moreover, modifications of scanner software may become necessary to enable display of metallic electrode contacts and tissues with large differences in density.

Future perspectives in regard to imaging

One of the major remaining challenges with cochlear implantation is to grasp the underlying causes for the large range of outcomes. Patients with similar demographics, medical history, type of cochlear implant and speech encoding strategy may show very
different speech perception scores. In post mortem studies it has been shown that the number of remaining ganglion cells has no relationship or a negative correlation to performance, indicating that performance variability cannot be explained on the basis of cochlear neuronal survival. [1,2] These findings and the fact, that the crude signal that is delivered by a limited number of channels of a cochlear implant can still be perceived as a meaningful auditory perception, gives rise to the supposition that processing the electrical/auditory input at a higher level in the auditory system is a main determinant for the final outcome. Several studies, in congenitally and prelingually deafened persons as well as in adults with later acquired deafness have indeed pointed to a reorganization of the auditory cortex during long lasting auditory deprivation. [3,4] This has been ascribed to the plasticity of the brain leading to colonization of the secondary/associative auditory cortex – normally used for auditory processing and language – by other sensory modalities. It implies that, although the auditory pathway to the primary auditory cortex remains functional, the incoming signals cannot be processed to meaningful sound in the higher order speech and language centers in many cases of prelingual deafness. [5,6] However, successful cochlear implantation in prelingually deaf adults has been demonstrated, but it is still difficult to assess candidacy in such cases. [7]

Magnetic resonance imaging provides a tool for morphologic and functional imaging of these cerebral areas and connections. Further investigations will have to prove whether changes in the functioning of the central auditory pathway might become a selection criterion for cochlear implant candidates. We are currently conducting a fMRI study to investigate phonological representation in both postlingual and prelingual deafened people.

Another important topic of inner ear research is otogenetics. Genetic causes account for about half of all cases of prelingual hearing impairment. The remainder is attributed to environmental factors, such as premature birth, infections or exposure to ototoxic drugs.

But also these have been shown to have genetic associations: eg mitochondrial DNA mutations are thought to underlie aminoglycoside-induced deafness [8] and genetic factors that may influence susceptibility to noise induced hearing loss are being discussed. [9] It is estimated that mutation of any of several hundred genes can result in deafness and to date over a hundred genes and loci have been identified. The aim to protect, restore or regenerate auditory neural function has instigated developments in gene therapy for hearing loss and cell delivery to the cochlea. [10] The role of high resolution computer
tomography scanning (microCT) and high field magnetic resonance systems in the development and monitoring of such treatment will have to be investigated.

The short term effects of surgical mechanical trauma to cochlear anatomic structures as well as the delayed loss of neural elements due to inflammation and other induced cell death pathways after implantation and electrical stimulation have been under investigation for a long time. Nowadays the widened application of cochlear implantation, including children and people with residual hearing, has further increased the alertness to cochlear trauma. Scientific studies and clinical reports emphasize the need for the development of atraumatic electrode designs, altered surgical techniques and thorough training of cochlear implant surgeons. So far such studies have mainly been the domain of histopathologists. Scarce reports describe the use of dynamic videofluoroscopy to investigate device-specific insertion characteristics in isolated temporal bones. [11,12] Cone beam CT of isolated temporal bones has been proven to render similar information concerning the position of the electrode as histological analysis. [13] Recently the application of high resolution micro-CT has been shown to provide practically artifact free images of isolated temporal bones and implanted devices over their total length. [14] Based on such micro-CT images we have investigated cochlear anatomic features, likely contributing to insertion trauma described with current electrodes. These findings may lead to reconsiderations on electrode design in regard to size and flexibility. Now, the challenge of in vivo assessment of cochlear trauma has to be faced. The data presented in this thesis underscore the potential role of radiology in the evaluation of electrode designs and surgical techniques in large cohorts of patients and with correlations to psychophysical data. However, direct visualization of the osseous spiral lamina is still not possible with current imaging techniques. In this thesis we have shown that the size of the scala tympani can be estimated based on the cochlear size and the correct positioning of electrode contacts can be supposed on midmodiolar CT sections. Recently cone beam CT has been reported to be superior to MSCT for in vivo imaging of cochlear implants because of its very high resolution and lower radiation dose. Despite these advantages, also in cone beam CT migration to the scala vestibuli has to be inferred from the position of the electrode contact in relation to the cochlear wall. [15]

Radiologic preoperative assessment of cochlear implant candidates has to be developed further. Whereas the mastoid and middle ear anatomy and anatomic variants are generally reported to guide the surgical approach to the temporal bone, the cochlea is usually only commented on if diseased. However, detailed analysis of the cochlear
anatomy will allow for precise and individualized planning of the insertion depth. We performed ex vivo studies on microCT and CT images confirming interindividual differences in cochlear size and form. Although estimations of length and diameter become within reach, the process is very time consuming and the current resolution of clinical scanners will limit the in vivo application. Further refinements in image processing will be necessary to improve automated segmentation of the inner ear and simplify measurements. Once this is achieved individual optimization of cochlear implantation might improve the outcome of speech perception scores. Furthermore, stock-taking of interindividual differences in cochlear form and size may justify the development of patient-specific electrode arrays in the future.
References


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