Novel applications of objective measures in cochlear implants

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Chapter 8

Summary

The treatment of severe to profound sensorineural hearing loss has rapidly evolved in the last several decades. The cochlear implant (CI) device, which forms an interface between a sound signal and the auditory nerve fibers (ANFs) of the deaf ear, is by now an accepted approach of rehabilitation for profoundly deaf individuals and generally achieves high performance in terms of speech perception. However, effectiveness still widely varies from person to person. Therefore, there is a continued impetus for further progress in CIs. In this thesis, we developed new applications of objective measures in modern CIs regarding electrically evoked compound action potential (eCAP) recording and electrical field imaging (EFI). With the development of an iterative deconvolution model, this thesis focuses on extracting the temporal firing properties of excited ANFs in human eCAP and evaluating their potential implications for clinical practice. In addition, this thesis describes an attempt to intra-operatively assess the placement of the electrode array within the cochlea based on impedance measurements.

Chapter 1 presents a general introduction to the basic principle of CI devices. Then the commonly used objective measurement tools in cochlear implantation are explained in more detail. At the end of this chapter, the outline of the present thesis is given.

Chapter 2 describes a study that constructs an iterative deconvolution model with two steps for estimating the human auditory unitary response (UR) and deriving the underlying neural excitation pattern of the excited ANFs. The recorded human eCAPs were entered as input for this model to estimate the human unitary response (UR) in the first step and obtain the compound discharge latency distribution (CDLD) that reflects the contributions from individual ANFs to human eCAPs in the second step. In this method, an eCAP was modeled by convolving a UR model with a CDLD model. Then, the modeled eCAP was optimized by iteratively manipulating the variables in the parameterized UR and CDLD models, until the modeled eCAP converged to the recorded eCAPs. With this method, the human UR and/or CDLD can be obtained automatically.

Chapter 3 describes the validation process by applying the iterative deconvolution model developed in **Chapter 2** to a relatively large dataset of human eCAP recordings, consisting of 4982 eCAPs from 111 CI recipients. With this model, a human version of the UR was estimated for the first time, which differs significantly from the guinea pig UR. With the estimated human UR, the CDLDs of 4660 eCAPs were validly extracted. Such CDLDs provided better estimates of the number of excited ANFs and their firing latencies. It was demonstrated that CDLDs had advantages over the more commonly used eCAP amplitude as they better reflected the temporal firing properties of excited ANFs. As the CDLD model with two Gaussian components was validated as the optimal model, the eCAP waveform can be described as a combination of a short and long-latency neural component (S-eCAP and L-eCAP). It was concluded that this iterative deconvolution was capable of deriving the temporal firing properties of excited ANFs underlying eCAPs, which may be clinically useful. As an example, significant differences in the temporal firing properties of excited ANFs between children and adults were found.

Chapter 4 investigates the potential clinical implication of eCAP waveforms by taking the temporal firing properties of the ANFs into account. This chapter reports on a retrospective study evaluating the effect of the temporal firing properties and the number of excited ANFs on the speech perception performance of 134 postlingually deaf adult CI recipients. With the iterative deconvolution model proposed in **Chapter 2**, the CDLD corresponding to each eCAP was obtained, and the number, peak latencies and the synchronicity of excited ANFs were calculated. It turned out that CI recipients with a larger number and greater synchronicity of excited ANFs tend to achieve better speech perception after implantation. On the contrary, the average latencies of CDLDs did not significantly affect speech perception. This study underlines the importance of taking temporal firing properties of excited ANFs in eCAPs into consideration when one investigates if eCAP recordings are indicative of speech outcomes.

Chapter 5 characterizes the refractory properties of ANFs underlying the S-eCAP and L-eCAP, and tests whether these refractory properties of children differ from those of adults as well as whether they are associated with speech perception. This retrospective study used the refractory recovery function recording obtained from 130 Hi-Focus Mid-Scala or 1J cochlear implant

(Advanced Bionics, Valencia, CA) recipients. We demonstrated that the auditory refractory properties of the S-eCAP and L-eCAP are different. We also found that these refractory properties were age-related, including that children show significantly shorter absolute refractory periods and larger saturation levels than adults. In addition, a trend that slower recovery of the S-eCAP was associated with better speech perception was found. Thus, it is worthwhile giving considerations to the two components of the eCAP in the future when assessing the clinical values of the auditory refractory properties for clinical purposes.

Chapter 6 reports a study that assessed whether the electrode impedance and the access resistance can be used to detect electrode translocation using electrical field imaging, and which metric is more feasible. A total of 100 subjects who received a HiRes90K cochlear implant with a Mid-Scala electrode were included in this study. The normal values of these two measurements were estimated as the baselines of the implant placed in the cochlea without translocation. The maximal electrode impedance deviation and the maximal access-resistance deviation from the respective baselines were calculated as detectors of translocation. It turned out that both metrics can reliably detect translocations. However, the access resistance had significantly greater accuracy and it also reliably detected the electrode-location of translocations. These measures can provide prompt feedback for surgeons after implantation, improving their surgical skills, and ultimately reducing the occurrence of translocations. In the future, these measures may allow near-real-time monitoring of the electrode array during insertion and help to avoid translocations.

Chapter 7 contains a general discussion of the results and the main conclusions of the studies presented in this thesis. Moreover, the clinical implications of the findings in this thesis and future perspectives are discussed.