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Exploring the capabilities of modern cochlear implants : from electrophysiology to quality of life

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Summary _____

**Exploring the capabilities of
modern Cochlear implants: from
electrophysiology to quality of life**

The treatment of acquired or congenital deafness has rapidly evolved in the last few decades. The development of an implantable system to restore stimulation to the inner ear has revolutionized the therapeutic approach and prognosis for those afflicted with profound sensorineural hearing loss. Although the electrical stimulation of the auditory nerve has received some criticism in the early days, cochlear implantation has now become an established technique to improve the ability of the profoundly deafened adult patient to understand speech. Since the 1980s, the speech reception results with cochlear implants have shown a continuous rise. But, just how good are the results of this treatment and is it possible to improve them further? This thesis describes the benefits of multi-channel cochlear implants with different measurements tools in the profoundly deafened adult, and the application of new features of modern cochlear implants to optimize speech perception.

In **Chapter one** the development and function of modern cochlear implants is described. The problems encountered during electrical stimulation of the remaining auditory nerve fibers in a deafened cochlea are explained in more detail. Toward the end of this chapter current concepts regarding objective and subjective measurement tools in cochlear implantation are discussed with special reference to electrophysiological measures, speech perception and quality of life.

In **Chapter two** the effects of cochlear implantation in the post-lingually deafened adult population are presented. A prospective evaluation demonstrated the benefits of cochlear implantation on speech perception, health related quality of life (HRQoL), and cost-utilities. Speech perception scores were determined using the Dutch Society of Audiology CVC (monosyllabic) word lists. Patients completed two questionnaires, the Health Utility Index Mark II (HUI2), a generic instrument, and the Nijmegen Cochlear Implant Questionnaire (NCIQ), a disease specific instrument. Utilities were obtained from the HUI2 and time trade off (TTO) instrument. Correlations between patient variables and benefit were calculated. To assess clinical relevance of cochlear implantation, this study was the first to examine both the Effect Size (ES) and the Minimal Important Clinical Difference (MID) for HRQoL items. The results showed a statistically significant improvement in HRQoL and speech perception ($p < 0.001$). The most important variables impacting speech perception were shorter duration of deafness and

higher educational level. Furthermore, it was concluded that the improvements in HRQoL items and speech perception were not only statistically significant, but also clinically relevant and cost-effective.

Chapter three investigates the benefit and performance of cochlear implantation in a small sub-group, the prelingually deafened adult population. Eight patients with prelingual deafness were included and were prospectively followed for at least two years. All patients filled in the Health Utility Index Mark II (HUI2) questionnaire and the Nijmegen Cochlear Implant Questionnaire (NCIQ). Speech perception scores were also determined. In addition, utilities were calculated using a visual analogue scale and the HUI2 instrument. Moreover, predictive factors were explored. It turned out that all subjects experienced improvement in several HRQoL items, and individuals could reach open set speech perception. We identified the quality of a patient's own speech production (QoSP) as a potential new selection criterion as this was positively associated with speech perception scores, although this study did not show statistical significance for any tested predictor of speech perception.

Because the QoSP depends on auditory input in the past, chapter 3 ends with the discussion whether we should abandon the classification "pre-, peri-, and postlingually deafened adult" and instead use the term "early deafened adult". In that way, we can concentrate on factors, like the QoSP, that may predict better performance with cochlear implants, rather than consider a patient as a potentially poor candidate when it is classified as "prelingually deafened adult".

Chapter four reports on a blind crossover study evaluating the effect of the number of electrodes (of the Clarion CII cochlear Implant) on speech perception in silence and noise using a "high-rate" continuous interleaving sampling (CIS) strategy. This study included 9 cochlear implant users with experience of an 8-channel CIS strategy (833 pulses per second per channel). The implant users were fitted in a random order with 8-, 12- and 16 channel high rate CIS strategy (1400 pulses per second per channel). After using each strategy for one month, speech understanding was tested in silence and noise. Patients' speech understanding in noise benefited significantly with high rate strategies, provided that the optimum number of electrodes was determined individually for each patient. Furthermore, patients with steeper learning curves tended to perform better with more electrodes.

One of the main conclusions of Chapter four is that individually optimized parameter selection (number of electrodes, stimulation rate, etc.) is essential to improve speech perception. As an alternative to subjective responses, objective measures may guide individual speech processor programming, especially in patient groups that are less cooperative like younger or multi-disabled patients. Many characteristics of the neural responses elicited by a cochlear implant can be verified through objective measurements. One such measure is the electrically evoked compound action potential (eCAP). In order to provide this objective information about implant performance, the latest cochlear implant models allow, through the implant itself, recording of eCAP from inside the cochlea (so called neural response imaging (NRI) or telemetry (NRT)). However, due to the short latency of the neural response, the stimulus artifact distorts the response waveform. The purpose of **chapter five** is to examine a new method for dealing with the stimulus artifact in electrically evoked compound action potential measurements in chronically implanted guinea pigs. An evaluation of the artifact identified two components: the recorded stimulus, and a prolonged potential due to residual charge of the electrode-tissue complex. We designed and introduced an amplifier with a compensation circuit that reduces the effect of the residual charge by electrical subtraction at the input. The new method allowed reliable recording of the eCAP. It had an additional advantage at higher stimulus levels, and for recording electrodes in the vicinity of stimulating electrodes. Furthermore, latency differences of the response waveform were observed between cathodic-first and anodic-first stimuli. As demonstrated by our data, the anodic- and cathodic-first versions of the forward masking paradigm produce different response signals. When the latency differences were analyzed in more detail, a close resemblance was observed between the outcome of the alternating polarity paradigm and the average of the outcome for anodic- and cathodic- first stimuli with the forward masking paradigm. It was concluded that implementation of the compensation circuit in future NRI/NRT systems could potentially broaden the clinical applicability and reliability of eCAP measurements. Chapter 5 ends by proposing a uniform and unambiguous nomenclature for the whole class of forward masking paradigms. This systematic approach appoints, in the case of the standard forward masking scheme, both masker (M) and probe (P) stimuli, as well as the number of frames (3) involved: MP3.

Chapter six describes a dual-masker forward masking technique and evaluates whether this objective method can assess electrode independence in a cochlear implant; more particularly, whether the optimal locations and number of active electrodes could be determined. We furthermore attempted to investigate the efficacy of current steering with this new technique, because the proposed recording method could also be described as applying a sequentially current steered masker. The new paradigm requires 5 frames involving 2 maskers and 1 probe and is referred to as the Apple Core method (MP5-AC). For each recording, both the masker and probe amplitude were varied independently, producing 3-Dimensional eCAP plots that showed the eCAP amplitude for independent variations of masker and probe amplitudes. A simple quantitative model was developed to aid interpretation of the results. Theory and model were clinically tested in 14 patients. On the basis of the model the multi-variate, color coded plots could be subdivided into seven distinct regions, each depicting a unique relationship between the probe and the maskers. The model's results supported interpretation of the clinical results, and predicted independence for the probe electrode contacts only at lower current levels and/or at greater inter-electrode distances. The clinical results revealed a lack of selectivity in the electrode array for stimulus levels larger than $600\mu\text{A}$. This suggests that sequential current steering is only applicable at higher current levels or smaller electrode distances. It was concluded that the MP5-AC paradigm provided insight concerning the independence of electrodes and the efficacy of current steering in clinical patients. However, its current clinical applicability is limited because measurements were adequate only in anesthetized patients.

Chapter seven contains a general discussion of the results and the main conclusions of the studies described in this thesis. Furthermore, implications for clinical practice and areas of future research are discussed.

