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Variables that Effect Psychophysical Parameters and Duration to Stability in Cochlear Implant Mapping

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Abstract

The process of rehabilitation after cochlear implant surgery involves programming the psychophysical parameters of the implant in a process called mapping. The audiology appointments involved in the mapping process are large contributors to cost of implant rehabilitation. The map is defined as stable when there is little variation over time. Once an implant map is stable there is reduced need for intensive rehabilitation and an increase in implant patient satisfaction. A literature search was conducted using the terms "map cochlear implant", "mapping cochlear implant", "psychophysical cochlear implant" with a date range from August 1957 to February 2016. A total of 560 articles were identified and 29 articles were retrieved for detailed evaluation. The most important factor identified, that determines map stability, is the patient's subjective implant experience. Patient demographics and implant variables have not been identified as significant. The second side implant in bilateral implantation has been shown to have significantly less time to map stability. There is a need for further studies to examine relationships between preoperative variables and the mapping process, rather than applying a "one size fits all approach", which is the current standard of care. This is of particular need in the setting of the second side in bilateral implantation.

Introduction

Hearing and speech perception for sensorineural hearing loss sufferers have been improved significantly since the advent of cochlear implantation [1]. Patients are required to perform audiological rehabilitation post implantation in order to achieve the best hearing outcomes. The process of rehabilitation and cochlear implant programming involves a process called mapping.

Mapping involves the measurement of a patient' physical responses to audiological stimuli with the resultant psychophysical profile termed the map. This involves generating a noise and asking patients whether they can hear it and to what degree. The psychophysical parameters that are measured include Threshold (T) scores, Comfort (C) scores and the Dynamic Range (DR) [2].

The T score is the quietest sound detectable that always produces a response by a given patient, the C score is the loudest sound that they can tolerate without discomfort for a sustained period of time, and the DR is the difference between these two values [2]. Psychophysical parameters are measured for each portion of the cochlear implant electrode array (the basal, medial and apical regions). This mapping stage is known to be a period of high variability in audiological responses, and requires close follow up by an audiologist with an average of 6 visits in the first year, with some institutions advocating for up to ten [3-5].

Map stability occurs when there is little variation in these parameters over time, and is assessed through audiological graphing of the data. Once a cochlear implant map is stable there is reduced need for ongoing rehabilitation, reduced need for intensive monitoring and an increase in implant satisfaction. Typically this period of variability requires six weeks to six months to become stable [3,6-9].

Patient audiological benefits are often balanced with the costs associated with cochlear implantation to justify the health economics, many such analyses take into account the direct and indirect surgical and device costs but do not directly evaluate the costs associated with rehabilitation afterwards [10-13].

Literature examining the duration of audiological rehabilitation and efficiency in cochlear implants have found the average duration of audiological visit to be 93 minutes, and given the frequency of visits post implantation, these costs are significant [14]. The time to achieve map stability directly impacts the number of post implantation audiological reviews and so it is important to identify what variables influence this. An understanding of the factors that affect map stability helps to inform decision making during the perioperative period and may also provide some cost efficiency with regards to rehabilitation.

Methods

A pubmed search using terms "map cochlear implant", "mapping cochlear implant" and "psychophysical cochlear implant" was performed with a date range of August 1957 to February 2016. A total of 560 articles were identified. Articles were screened for title and abstract only with a total of 29 articles retrieved for a more detailed evaluation. Articles reviewed were limited to the English language.

Discussion

Most cochlear implant centers apply a "one size fits all approach" to the mapping process [5]. This leads to a failure to identify, and potentially address, outliers until they are failing to stabilize within the usual time. Very few studies report on medium to long term psychophysical characteristics of cochlear implant audiological rehabilitation which limits the ability to understand the true effect of variables on the mapping process. Factors that have been examined in the literature in relation to map stability include subjective patient feedback, age, gender, etiology of deafness, duration of deafness, array type, and sequence in bilateral sequential cochlear implantation.

Subjective patient feedback

Most centers rely mainly on the patient's subjective feedback as a basis for the mapping changes, which is interesting considering most clinicians do not believe the patient's subjective experience leads to optimal cochlear implant performance [5]. In a global survey of cochlear implant center mapping practices, it was found that the average center schedules three sessions in the first three months, three sessions in the following nine months, and another one annual session thereafter [5]. The majority of time, in these appointments, is spent with verification and adjustments to optimize loudness. Most centers rarely spend time adjusting map parameters other than minimum and maximum levels in follow up appointments. The most important factor that determines map stability is the patient's subjective implant experience. This of course is difficult to quantify but there are a number of potential factors discussed below that contribute to this.

Age

Age, as a predictor of cochlear implant audiological outcomes, is reported in the literature with different effect. Some of the published literature indicate that older age at implantation relates to poorer audiological outcomes [15,16]. Most studies examining the specific effect of age however have not shown any significant effect [4,17,18]. One study suggested a difference between adults and children in the first six months, with comfort levels showing significant change but beyond six months the levels were stable [19]. This did not change the overall time to map stability and was thought to be due to the fitting method used in children rather than actual psychophysical differences. It is possible that the effect of age at implantation on audiological outcomes in the studies mentioned above, may be in part reflecting a longer duration of deafness rather than a pure effect of age on outcome. From the information in the literature it seems that while age may contribute to the audiological outcome of the cochlear implant, it has little long term effect on the mapping process.

Gender

From examining the few studies that have examined the relationship between gender and audiological outcomes, psychophysical parameters and stability duration, there is no significant effect of gender [4,17].

Etiology of deafness

Establishing an effect of etiology of deafness and psychophysical parameters and stability is often challenging, given that frequently the cause of deafness is unknown. Because of the lack of most studies to differentiate etiology, there is yet to be any identified conditions that definitively have a significant effect [3,4,20]. A few specific conditions have been identified as likely having particular effects on elements of the psychophysical parameters. The T score has been associated with the presence and type of tissue present within the cochlear, with pathological tissue growth within the cochlear being associated with increased T scores and a reduced DR score [21,22]. Conditions associated with ganglion cell survival may show a relationship between number of surviving neurons and improved C scores [20]. The degree to which pathological tissue or nerve cell survival impacts on duration to stability however has not been assessed.

Duration of deafness

It is well established that the longer the duration of deafness the poorer the audiological outcomes with cochlear implantation [16,17,23-25]. Prolonged auditory deprivation has been considered to be a significant factor in reducing the benefit potentially received by cochlear implantation, and is the foundation for the recommendation of preoperative hearing aids [26]. Dynamic ranges have been found to be reduced with deafness greater than 10 years, which may influence satisfaction with the implant [20]. Duration of deafness has not been shown as a significant variable for time to map stability [4].

Array type

One small study compared perimodiolar arrays to straight electrode arrays in the same individuals who had bilateral implantation first with one and then another electrode array type. As might be expected, compound action potential thresholds, T levels and C levels were lower in perimodiolar arrays but there was not any significant difference in dynamic range [27]. This study did not follow patients for long enough to comment on timing for stability, but given the lack of difference in dynamic range between array types, it would be unlikely to be an important variable for map stability.

The second side in bilateral cochlear implantation

In the current health economic climate of first world countries, many researchers are investigating to justify the cost effectiveness of bilateral cochlear implantation. Bilateral implantation have added benefits (over unilateral) to recipients with bilateral profound hearing loss including improved sound localization and speech perception in noise [28,29]. This follows on to provide improved quality of life in a way that can be measured as a positive over the economic cost [10-13]. A randomized control trial on cost utility of bilateral implants concluded that bilateral implants is cost effective if the patient has a life expectancy of five to ten years or longer [30]. Interestingly, the majority of cost analyses of bilateral implantation are yet to incorporate the costs associated with implant rehabilitation and mapping. When examined as a primary outcome, the time for map stability has been defined as significantly shorter on the second side [4]. There was a reduced time to achieve stability on average by 36 days in the second implant (87 days for first implant and 51 days for the second implant) [4]. Potential explanations for faster duration to achieve stability include faster neural pathways and neuroplasticity resulting from prior experience and practice relating to the first implant mapping process. Prior learning has been shown to be fundamental in the development of new neural pathways [31]. Other proposed mechanisms include patients being more familiar with the process and what auditory stimuli sound like. It is recognized that initial auditory stimuli is often labelled as uncomfortable or not tolerable relating to inexperience and unfamiliarity with tones, and that with experience these tones become recognized as acceptable [32]. All these potential explanations tie back to the patient's subjective experience being the most likely factor affecting time of map stability. Despite this significantly reduced duration and the costs associated with audiology follow up, many institutions do not alter the mapping process for the second side in bilateral implantation.

With consideration to mapping, a unique issue to the second implanted side is that of the user needing to fuse the information of both implants into a single sound stimuli. Failure to do this by the patient leads to sounds seeming unbalanced with a single sound source being perceived as separate [33]. Balancing not only involves loudness but also localization of the sound source. Fusion of the sound information can take time, although how long is needed is undefined. There has been a suggestion that new mapping procedures and signal processing strategies are needed, for the second implant in bilateral implantation, to allow for better fusion between them [33-35]. Another potential for delay in the second side is that electrodes mapped to the same frequency range in each ear may stimulate different locations in each cochlea due to an insertion depth difference of each electrode array. This also can account for poor sound image fusion [36]. It is recognized that the timing of the second implant, particularly in pre lingual children, is important for outcomes including central processing and language development [37]. It has not been reported whether this translates into comparably longer mapping times for the second implant. If these factors where adapted into a mapping process designed for the second side in bilateral implantation, the time for map stability could even be potentially shorter.

As described above, since the patient's subjective feedback is the major tool in an audiology mapping session, it seems plausible why only limited variables have been directly linked to timing for map stability and that in the case of the second implant a patient benefits from having already experienced a first implant [4].

Other potential variables

A number of other factors have been identified as effecting the audiological outcomes of cochlear implantation including pre-lingual compared to post-lingual deafness, the presence of residual hearing, the coding strategy used and the implant manufacturer [38-39]. These have yet to be examined with regards to mapping and would benefit from being investigated in future research.

Conclusion

The time it takes to map stability contributes greatly to the cost of post-operative rehabilitation in cochlear implantation. The greatest factor in determining map stability is the patient's subjective experience. Because this is difficult to quantify, there is a need for further studies to examine relationships between preoperative variables and the mapping process so that these can be factored into the mapping planning, rather than applying a "one size fits all approach", which is the current standard of care. This is of particular need in the setting of the second side in bilateral implantation.

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