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Research Paper

Challenging aspects of contemporary cochlear implant electrode array design

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KEYWORD
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Abstract *Objective:* A design comparison of current perimodiolar and lateral wall electrode arrays of the cochlear implant (CI) is provided. The focus is on functional features such as acoustic frequency coverage and tonotopic mapping, battery consumption and dynamic range. A traumacity of their insertion is also evaluated.
Methods: Review of up-to-date literature.
Results: Perimodiolar electrode arrays are positioned in the basal turn of the cochlea near the modiolus. They are designed to initiate the action potential in the proximity to the neural soma located in spiral ganglion. On the other hand, lateral wall electrode arrays can be inserted deeper inside the cochlea, as they are located along the lateral wall and such insertion trajectory is less traumatic. This class of arrays targets primarily surviving neural peripheral processes. Due to their larger insertion depth, lateral wall arrays can deliver lower acoustic frequencies in manner better corresponding to cochlear tonotopicity. In fact, spiral ganglion sections containing auditory nerve fibres tuned to low acoustic frequencies are located deeper than 1 and half turn inside the cochlea. For this reason, a significant frequency mismatch might be occurring for apical electrodes in perimodiolar arrays, detrimental to speech perception. Tonal languages such as Mandarin might be therefore better treated with lateral wall arrays. On the other hand, closer proximity to target tissue results in lower psychophysical threshold levels for perimodiolar arrays. However, the maximal comfort level is also lower, paradoxically resulting in narrower dynamic range than that of lateral wall arrays. Battery consumption is comparable for both types of arrays.
Conclusions: Lateral wall arrays are less likely to cause trauma to cochlear structures. As the current trend in cochlear implantation is the maximal protection of residual acoustic hearing, the lateral wall arrays seem more suitable for hearing preservation CI surgeries. Future

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development could focus on combining the advantages of both types: perimodiolar location in the basal turn extended to lateral wall location for higher turn locations.

Introduction

An electrode array is the essential part of a cochlear implant (CI).It is inserted into the cochlea of the inner ear in the near proximity of auditory nerve fibres and allows their electrical stimulation, Fig. 1. The design of a CI electrode array as well as its exact intracochlear position determines to great extend sound audibility with the CI technology. While the external part of CI, containing an audio processor, can be upgraded in line with technological development, the implanted electrode array remains inside the cochlea typically for the whole duration of implantation. Such intended long-term implantability puts high requirements on array's biocompatibility, durability and its functional design as it cannot be changed easily. At present, more than 20 years since the introduction of such hearing restorative treatment to clinical practice, the surgical implantation has reached very a traumatic levels. On the one hand, such a traumacity was achieved by improving the design of the array making it maximally compatible with the anatomical shape of the cochlea. On the other hand, the surgical advancement has minimised trauma during the insertion process, maximally protecting the intracochlear cellular structures. The cochlear implantation has therefore become a gold standard for the treatment of all sorts of deafness forms, which cannot be helped by conventional hearing aids. The CI candidacy nowadays extends extensively the original group of profoundly deaf persons and includes also patients with significant levels of residual hearing.

All current CI electrode arrays have evolved along two distinctive design concepts. More common are so called lateral wall electrode arrays. These are free-fitting arrays occupying space in scala tympani in their final location just under the organ of Corti next to the lateral wall. On the contrary, the second class, perimodiolar electrode arrays, are located along the cochlear modiolar wall to minimise the distance to the modiolus to increase stimulation specificity and reduce battery consumption. To reach such a specific location, perimodiolar arrays are typically pre-shaped and implanted with the help of a stiffening element to keep the array relatively straight as needed for insertion. The array resumes its curved form after a removal of the stiffening element when insertion is advanced far enough. Examples of both types of arrays are given in Table 1.

Perimodiolar electrode arrays can hug the modiolus only in the basal turn where it has a diameter large enough to resist its wrapping with an electrode array. Therefore, they are relatively short and cover mainly the basal turn. Furthermore, as these arrays are mostly inserted through the cochleostomy, typically drilled some distance from the round window, they don't wrap the most basal part of the modiolus and the distance to it might be larger than for the lateral wall arrays in this cochlear region.[1] In the future developments, it would be desirable to design a perimodiolar electrode array which continues in higher turns along the lateral wall, where modiolus is too fragile, to provide the complete cochlear coverage of required acoustic frequencies.

Discussion

1. Complete cochlear coverage not only for Mandarin-speakers

Tonal languages such as Mandarin require that CI transmits highly effectively also temporal information about low

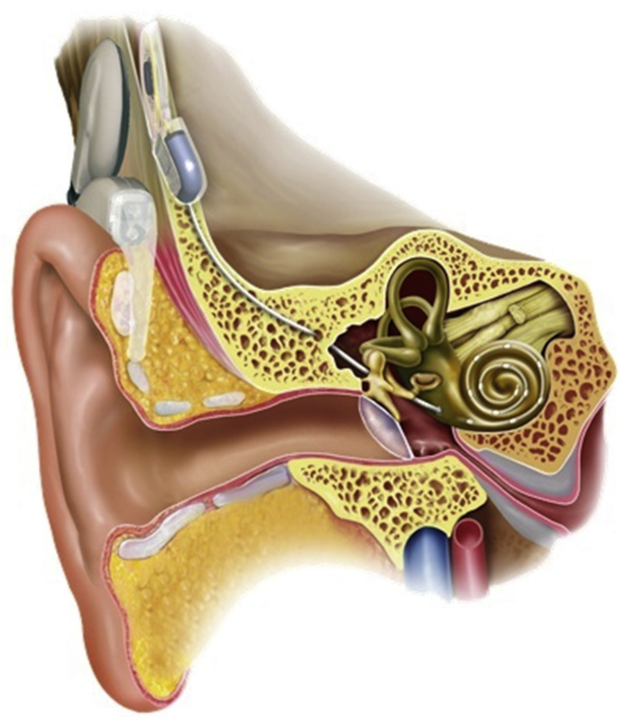

Fig. 1 Schematic representation of the cochlear implant. The behind-the-ear external processor with ear hook and a battery case uses a microphone to pick up sound, converts the sound into a digital signal, processes and encodes it into a radio frequency (RF) signal and sends it to an internal receiver placed under the skin behind the ear. A hermetically sealed stimulator decodes the signal using power derived from the RF signal, converts it into electric currents and sends them along wires into the cochlea. The electrodes at the end of the wire stimulate the auditory nerve fibres. Such electrical impulses are interpreted in the central nervous system as sound.

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