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Review Article

Is it possible to achieve zero frequency-to-place mismatch?

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Abstract

In recent years the relationship between the normal tonotopy of the cochlea and the distribution of bands in the frequency range of the cochlear implant are discussed, and also are considered the possibility of tonotopic fitting. Tonotopic fitting is a reduction of the discrepancy between normal tonotopy and the frequency range of the cochlear implant. There are indications that with the best match, speech intelligibility is higher. In this paper, the possibilities of tonotopic fitting of a speech processor for various Med-El implants are considered at the example of a cochlea with a cochlear duct length of 35 mm.

Keywords: Cochlear implant; Tonotopy; Frequency-to-place mismatch; Frequency range; Full coverage

Introduction

In recent years, the relationship between the normal tonotopy of the cochlea and the distribution of bands in the frequency range of the cochlear implant and the possibility of tonotopic fitting are discussed. Tonotopic fitting is reducing the discrepancy between tonotopy and the frequency range of the cochlear implant. There are indications that, with the best match, speech intelligibility is higher [1,2]. After the complete insertion of any electrode chain, the electrodes fall into places with a characteristic frequency determined by the cochlear duct length (CDL) and the electrode chain. In 1998, we wrote that in the vast majority of cases, the frequency bands of the implant do not coincide in their location with the frequency bands of the normal cochlea in accordance with its tonotopic organization [3]. In this paper, the possibility of tonotopic fitting of a speech processor for various Med-El implants using the example of a cochlea with a cochlear canal length of 35 mm, is considered.

In S.-Pb ENT Institute, during cochlear implantation a standard chain of 12 implant electrodes with a length of 31.5 mm were inserted completely in the vast majority of cases. Some problems with incomplete insertion were partially solved after my suggestion to slightly turn the electrode chain clockwise and counterclockwise. After performing such a twist, the electrode chain easily moved deeper into the cochlea [4]. To determine the relation of cochlear tonotopy and spectrum separation along the implant channels, it is necessary to consider the actual position of different electrode chains in the scala tympani and evaluate which bands of this frequency range of the implant stimulate which frequencies of the auditory nerve in accordance with the cochlear tonotopy. In the Curtis D.P. review [5], the average length of the cochlear canal from 2252 samples was 33.04 mm. The range is 28.2-36.4 mm. In our paper, we will consider a position of implanted chains of 12 electrodes in a cochlear duct length (CDL) of 35 mm. Calculations of the location of the electrodes in the cochlea were carried out using the Greenwood D. formula for 35 mm duct [6]. When considering different implants, we relied on photos of different electrode chains and cannot guarantee calculations with an accuracy of 0.5 mm, but the picture we examined accurately represents the actual position of the electrodes in the cochlea of 35 mm length. In our work, we evaluated the position of the first and 12th electrodes of the implant. We considered the ratio of tonotopy and spectrum division into bands at the frequency range of the implant 70-8500 Hz.

The central frequency of channel 12 is 7400 Hz in this frequency range. After the complete insertion of a standard electrode chain of 31.5 mm length, the 12th electrode is located at a distance of about 4 mm from the cochleostomy. This coordinate, according to the Greenwood D. formula, corresponds to a characteristic frequency of about 12 kHz. Therefore, the difference from normal tonotopy is 12000-7400 = 4600 Hz. After complete insertion of the implant, the 1st electrode is located at a distance of 30.4 mm from the cochleostomy, which corresponds to a characteristic frequency of 146 Hz. The central frequency of the first channel in the frequency range of 70-8500 Hz is 128 Hz. I.e., the first electrode lies in good accordance with the tonotopy of the cochlea. As follows from these positions of the first and twelfth electrodes, the frequency difference between tonotopy and band distribution in the frequency range of the implant will increase from the first channel to the 12th.

Is it possible to achieve a coincidence of the cochlear tonotopy and the central frequencies of the bands in the frequency range of the implant 70-8500 Hz? In the FLEX34 implant, the length of the electrode chain is increased due to the greater distance between the electrodes. If a FLEX34 chain is inserted, the frequency discrepancy with the tonotopy at the 12th electrode will remain the same — about 4.6 kHz. The central frequency of the 1st channel 128 Hz will fall on the characteristic frequency of 70 Hz. 3rd-4th electrodes will lie on the tonotopic place, and then the frequency discrepancy will increase to the 12th electrode. If FLEX34 is inserted into the cochlea with a CDL greater than 35 mm, then the first electrode will lie more precisely on the tonotopic, and the discrepancy with the tonotopy at the 12th electrode will increase.

If a short FLEX28 or FLEX25 is inserted into a 35 mm length cochlea, then the discrepancy between the tonotopy and the central frequency of the 12th channel will remain the same (4600 Hz), since the distance from the cochleostomy to the 12th electrode is approximately the same for these implants. And the central frequencies of the remaining channels will shift to higher characteristic frequencies. If you insert FLEX25 or FLEX28 into the cochlea with a smaller than 35 mm CDL, then the first electrode will lie more precisely in tonotopy, and 12th with a difference of 3-4 kHz. If you inserted a short FLEX24, the frequency discrepancy at the 12th electrode will increase in comparison with FLEX25-34, because the distance from the cochleostomy to the 12th electrode in the short FLEX 24 is less than in FLEX25-34. And the central frequencies of all other channels will shift to higher characteristic frequencies of cochlea even in comparison with FLEX28 and FLEX25. If you inserted a FLEX24 in cochlea with a length, less than 35 mm, then the first electrode will lie more precisely in tonotopy, and the 12th with a difference less than in CDL 35 mm.

As can be seen, after the complete insertion of any chain of electrodes, the coincidence of the tonotopy and the central frequencies of the bands in the frequency range of the implant cannot be achieved, since frequency perception occurs according to the place theory [7], and the boundaries of the frequency bands cannot be set in accordance with the position of the electrodes in the cochlea. That is, none of the existing chains of electrodes from Med-El company provides a clear tonotopic adjustment at CDL 35 mm and a FR of 70-8500 Hz. Similar frequency-to-place mismatches are found in other CDL. It follows that the main task of fitting, taking into account the anatomy of the cochlea, is to select the chain of maximum length with the maximum possible distance between the electrodes, which can be inserted into this cochlea in order to maximize its coverage [8]. To achieve a better match between the normal tonotopy of the cochlea and the distribution of bands in the frequency range 70-8500 Hz of the implant, this option can be considered. If you move the entire FLEX31 chain to 2.5 mm deeper into the cochlea, then the 12th electrode will be at a distance of 6.5 m from the cochleostomy and it will fall at a characteristic frequency of about 8 kHz. This is close to the central frequency of the 12th channel in frequency range of 70-8500 Hz. But the first electrode lies at a characteristic frequency of 70 Hz, which is slightly different from the central frequency of the first channel — 128 Hz — in this frequency range. There is some discrepancy, but in the proposed variant, the maximum coincidence of the tonotopy and the position of the FR bands is achieved. Thus, in order to achieve a better match of the tonotopy with the bands in the FR 70-8500 Hz at a CDL of 35 mm and an implant length of 31.5 mm, it is necessary to increase the distance from the cochleostomy to 12 electrodes from 4 to 6.5 mm.

Another way to achieve the matching of tonotopy and bands of CI frequency range is an expanding the FR of the implant. In order for the central frequency of channel 12 to coincide with the tonotopy, it is necessary to increase the frequency range of the implant to 14 kHz but this is out of the question, because as we have suggested and shown, even the frequency range of 70-8500 Hz is not the best for speech perception [9]. When the FR is expanded to 14 kHz, high frequency components carrying little information will be added and the width of all single-channel bands will increase, which will significantly reduce the channel selectivity of stimulation (CSS) [10]. A decrease in CSS will entail a noticeable deterioration of speech intelligibility. Such a wide FR is not used in CI. When considering the issue of tonotopic fitting, the frequency range of the implant should be taken into account, on which speech intelligibility largely depends [9, 10]. Naturally, for different FR, the frequency-to-place mismatch will differ, since regardless of the FR, each electrode of the chain is located in the same place and stimulates only its frequency zone of the cochlea.

As we have shown, the best frequency range for speech perception is the FR of 200-6500 Hz [11]. With such a FR in a cochlea with a 35 mm CDL, the frequency-to-place mismatch will be significantly greater than with a FR of 70-8500 Hz. The difference between the tonotopy and central frequency of channel 12 at FR 200-6500 Hz is 6.3 kHz. If some implant with a FR of 200-6500 Hz is positioned in the cochlea so that the central frequencies of the bands of the 1st and 12th channels fall on equal characteristic frequencies in accordance with the tonotopy of the cochlea, then for a cochlea with a length of 35 mm, the 12th electrode should lie at a distance of 9.1 mm from the cochleostomy, and the first electrode at a distance of 28.5 mm. The distance between the 1st and 12th electrodes will be 19.4 mm and, therefore, the distance between the individual electrodes will be 1.76 mm, which is significantly less than the standard 2.4 mm in a 31.5 mm implant. Naturally, in comparison with the standard electrode chain, the interference of channels will increase, which will worsen the perception of speech.

As for the results of speech perception by CI patients with frequency-to-place mismatch, it is necessary to refer to the results of adult post lingual patients. In the first days after fitting up, they have complaints about the quality of speech, but later they say that they hear as before. Moreover, they definitely do not have a coincidence of tonotopy and FR bands, because I set the FR from 250 to 6500 Hz. That is, they somehow complete the impoverished speech to a normal picture. Prelingual children, of course, do not have the opportunity to compare a new implanted picture of speech with anything. They are just successfully mastering a new implanted language. I also set their FR from 250 to 6500 Hz, and therefore, with an implant length of 31.5 mm, there is no question of matching the tonotopy and FR bands. At a frequency range of 250-6500 Hz, the difference between the tonotopy and the FR bands in channel 12 is 6.3 kHz. There are more than 7,000 languages in the world that differ significantly from each other, but they are all understandable to their owners. It is difficult to understand what signs they use to understand, but they are undoubtedly different. In the 20th century, another language appeared — implanted, which is understandable to CI patients. It is interesting to note that all implanted patients hear (perceive) it differently, but they all understand their native language (some understand a foreign language) and speak it, despite the significant frequency-to-place mismatch.

As for completing the perception of spectrally deprived speech, comb filtering can (CF) be considered. In our work on the study of speech perception processed by a comb filter, we used 5 bands with a width of 50 Hz, located in different places of the few frequency ranges from the band 70-8500 Hz [9,11]. Depending on the range used, from 3 to 4% of the speech signal spectrum remained after the CF processing. Naturally I listened the processed speech material. At first time I did not understand all the words, and after a while, when listening to the speech processed by CF, represented by 5 bands of 50 Hz, to my surprise, I did not find much difference from speech with a full spectrum. I.e., by analogy with CI patients, some kind of restructuring of perception took place and the words with the absence of 96-97% of the spectrum, were heard completely. It's fine. Our MIMIC demo program also serves as a confirmation of the restructuring of perception [12]. Based on these considerations and the parallels between CI and CF [13], a new method for measuring speech intelligibility can be proposed. Initial results on its use, obtained on subjects with normal hearing [9, 11], provide grounds for testing this method on CI patients.

As for implants from other Companies, the issue of compliance with the normal tonotopy and frequency bands of the implant requires separate consideration. We can only say a few words about Cochlear direct implants. Unlike Med-El implants, where the distance between the 1st and 12th electrodes is 26.4 mm, in straight Cochlear implants the distance between the 1st and 22nd electrode is approximately 15 mm and, therefore, the chain covers less than half of the cochlear canal. Naturally, it is impossible to talk here about the correspondence of normal tonotopy and the division of the frequency range of the implant into bands. Despite the significant differences in the direct electrode chains (hence, the frequency-to-place mismatch) of Cochlear and Med-El, patients with implants from these companies do not differ in rehabilitation results. As can be seen from our presentation, it is quite a difficult task to achieve the coincidence of the tonotopy and the central frequencies of the electrode chain in CI-patients. Each cochlea needs its own chain.

We agree with many authors that the main CI preoperative task is to choose implant of the maximum length that can be completely inserted into this cochlea in order to maximize its coverage [14, 15]. The calculations of the insertion depth according to OTOPLAN coincide well with the actual position of the electrode chain after the operation [16]. Preoperative planning of the surgical intervention trajectory is also carried out according to the results of OTOPLAN [14]. The OTOPLAN program can be used in robotic surgery [14, 17].

Conclusions

It is possible to achieve the zero frequency-to-place mismatch only with the help of special chains of electrodes-each cochlea needs its own chain in definite CI frequency range.

The main task of fitting, taking into account the anatomy of the cochlea, is to select the electrode chain of maximum length, which can be completely inserted into the cochlea in order to maximize its coverage.

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