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Amplitude Frequency Temporal picture of a New Implanted Language

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Abstract

The beginning of cochlear implantation (CI) was laid in France in 1957 [1]. Since then, CI has made great progress. Miniature behind—the-ear and wireless speech processors have been developed, multielectrod chains that completely cover the cochlea, new coding strategies have been developed - CIS, SPACE, FS-4, etc., power and information transmission are carried out over the radio channel, new batteries, brainstem implants, fully implantable devices and much more are being created. But the essence of CI has remained the same — electrical stimuli excite the fibers of the auditory nerve, and the deaf patient hears. And what does he hear? This article examines how the sound signal is processed in the CI, how the nerve is stimulated, and what the implanted patient perceives. We discussed this issue earlier [2]. The author of the article, a biophysicist, has 20 years of experience working with more than one thousand implanted patients and their parents. Several patents have been obtained on the subject of CI.

Keywords: Cochlear Implantation; Tonotopy; Frequency Range; Bandpass Filtering; Threshold Level; Frequency to Place Mismatch.

The beginning of cochlear implantation (CI) was laid in France in 1957 [1]. Since then, CI has made great progress. Miniature behind-the-ear and wireless speech processors have been developed, multielectrode chains that completely cover the cochlea, new coding strategies have been developed - CIS, SPACE, FS-4, etc., power and information transmission are carried out over the radio channel, new batteries accumulators, brainstem implants, fully implantable devices and much more are being created. But the essence of CI has remained the same — electrical stimuli excite the fibers of the auditory nerve and the deaf patient hears. And what does he hear? This article examines how the sound signal is processed in the CI, how the nerve is stimulated, and what the implanted patient perceives. We discussed briefly this issue earlier [2]. The author of the article, a biophysicist, has 20 years of experience working with more than one thousand implanted patients and their parents. Several patents have been obtained on the subject of CI. In the following, as an example, we will rely on an optimally fitted standard Med-El implant, which has the most comfortable level (MCL) set at 1000 current unit (cu), a threshold current level of 100 cu (10% of the MCL), a frequency range of 70-8500 Hz, 12 channels, and a processor trigger threshold level of 40 dB SPL.

Audio signal processing

At each moment of time, the speech (sound) signal has a certain instantaneous spectrum. This instantaneous spectrum is divided into 12 frequency bands of a certain width in the Med-El speech processor, energy is measured in each of them, and electrical impulses are created in accordance with its magnitude in each of the 12 channels. These impulses in a certain order stimulate the areas of the auditory nerve in which the electrodes are located, and each of the impulses causes a certain auditory sensation, which differs in spectral sensation in different channels from different electrodes. Obviously, in implanted patients, the normal speech spectrum is significantly transformed. It is clear that the implanted patient perceives the transformed instantaneous speech spectrum as a sensation from a certain number of frequency bands (for Med-El–12), and the speech pattern over time as a change in sensations from successive patterns of the instantaneous spectrum. As we have accepted, the instantaneous spectrum changes 1000 times per second.

Let's consider what kind of sound signal an implanted patient perceives as a result of CI processing. At a processor trigger threshold level of 40 dB SPL (our example threshold level is 100 cu), the patient hears a sound of threshold intensity. If such an implanted patient has a threshold tonal audiometry, then looking at the audiogram obtained, we can say that he has the first degree of hearing loss. But this is absolutely wrong, because it does not correspond to the first degree of hearing loss in terms of surdology, and such a statement deceptively misleads parents of CI patients.

For example, because a patient with first-degree sensorineural hearing loss can distinguish dozens of tonal signals by frequency [3] and an implanted patient can distinguish only a certain number of band-pass signals, equal in number to the number of electrodes. Moreover, such an "audiogram" can be obtained with great success even if the setting is incorrect, namely, when the current thresholds recorded in the processor program are too high [4]. For example, at electrical threshold levels of 200 cu, i.e., 20% of the MCL of loudness. With such incorrect settings of the threshold current levels, it is undoubtedly easier for the patient to detect sounds at the processor trigger threshold level of 40 dB SPL, but it worsens the discrimination of sounds by intensity, because the sound range processed in the implant is distributed not in 900 cu, but in 800. This «compression» naturally has a negative effect on speech intelligibility. We discussed the question of the possible use of the results of pure tone audiometry in fitting earlier [4].

The last similarity of CI patients and patients with the first degree of sensorineural hearing loss should be noted. There is a phenomenon of accelerated loudness increase (recruitment) in both groups of patients since, as we wrote earlier, the mechanism of this phenomenon lies in the fibers of the auditory nerve [5,6]. Next, we will describe the differences between a patient with an implant and a person with normal hearing. A patient with hearing loss also has all these differences with CI patient.

Frequency Range

The boundaries of the frequency range (FR) are set at the first connection. That is, unlike the norm, the processed frequency range is initially limited (!). The maximum FR for Med-El is 70-8500 Hz by default. However, it cannot be argued that the wider the FR, the better the perception of speech. Comparing models of implants with different FR, we used a new method for measuring speech intelligibility and found that speech intelligibility in the frequency range of 70-8500 Hz is lower than in narrower FR [7]. When considering the contribution of various spectral bands to the perception of speech in the norm [8], we also came to the conclusion that this wide FR is not the best for speech perception. The need to narrow the FR for better speech perception is indicated precisely by the band processing of the speech signal and the perception of bands. Narrowing the single-channel bands improves the channel selectivity of stimulation. We discussed this earlier [9]. There are indications that a wide FR has disadvantages in perceiving speech in noise.

The frequency difference between tonotopy and bands distribution in the frequency range of CI. (frequency-to-place mismatch). The frequency of stimulation is the same in all CI channels - in our example, 1000 Hz. Therefore, according to the time theory, patients should hear a band with a central frequency of 1000 Hz in all channels, but this is not observed - they hear different sounds from different electrodes, and also in low-frequency channels. The perception of the frequency of stimuli by implanted patients confirms the place theory of a frequency perception.

When comparing the frequency of stimuli in patients with unilateral sensorineural hearing loss we found that 500 Hz on the affected side is equal to 610 Hz in the healthy ear. This shift in frequency perception is not explained by the temporal theory of low frequency perception, but only by the theory of place [10]. Patients with Med-El implants perceive 12 bands, the central frequencies of which correspond to the frequencies at which the electrodes are located in accordance with the normal tonotopy of the cochlea. Moreover, this perception of frequency does not depend on the boundaries of the frequency range. In the implant we are considering, in the frequency range of 70-8500 Hz, the central frequency of channel 12 is 7400 Hz. According to the D. Greenwood formula [11], after the complete insertion of the electrode chain, the twelfth electrode will lie at a characteristic frequency of about 12 kHz. Therefore, the difference from the normal tonotopy for channel 12 is 12000 - 7400 = 4600 Hz. The central frequency of the first channel is close to the tonotopic frequency [12]. As follows from this arrangement of the first and twelfth electrodes, the bands perceived by the patient do not coincide with the bands of the instantaneous spectrum of the signal in most channels.

The difference between the tonotopy and the location of the bands depends on the frequency range. For example, in the FR 250-6500 Hz used by us, the frequency difference between the tonotopy and the central frequency of channel 12 is 12000-5727 =6273 Hz [12], on the first channel -145 Hz in tonotopy, and 289 Hz in FR division. And despite this, some parents highly appreciate our fittings and come to us to fit CI of their children. And they even come for the first connection.

As we noted earlier, it is quite a difficult task to achieve the coincidence of the tonotopy and the central frequencies of the electrode chain. Each cochlea needs its own chain [12]. Using the tonotopic fitting, it is impossible to achieve a complete coincidence of the tonotopy and the bands of the instantaneous spectrum of the input signal. We agree with many authors that the main preoperative task is to select the maximum length of the electrode chain that can be completely inserted into a given cochlea in order to maximize its coverage [13]. If we look at the strategy of PPS (pulse paired stimulation) stimulation with a pair of stimuli of different electrodes at the same time, then the time-frequency pattern of speech changes radically.

Time delay of perception of high-frequency and low-frequency bands.

In addition to the fact that there is a discrepancy between the normal tonotopy of the cochlea and the distribution of spectral bands in the frequency range of the implant, there is another significant difference between CI-stimulation and the norm. Namely, there is a different time delay in stimulation of the auditory nerve with stimuli of different frequencies in normal

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and in patients with CI when these stimuli are simultaneously delivered to the oval window in normal ear [14] and in CI patients after processing the instantaneous spectrum. We already mentioned this difference in a 1998 article [2].

If, as we assumed, the instantaneous spectrum is transmitted 1000 times per second at each electrode, then it turns out that the low frequency band of the instantaneous spectrum of the first channel stimulates the fibers of the auditory nerve with a delay of one millisecond relative to the high frequency band. Normally, as in CI patients, the perception of the instantaneous spectrum of the signal also begins with high frequencies, but there is a non-linearly increasing time delay in stimulation by increasingly low-frequency components of the instantaneous spectrum. For example, a stimulus with a frequency of 300 Hz is perceived more than 3 milliseconds later than a stimulus with a frequency of 5500 Hz, provided that they simultaneously enter the oval window [14]. A significant difference from the CI of patients.

As you can see, the transformation of speech in the implant is huge - there are no common features left from the normal speech pattern with the speech signal that CI patients hear. Post-lingual patients evaluate the new implanted language firsthand and note a significant difference with the normal speech signal. There is nothing like this in any of the more than 7,000 world languages - we can definitely say that implanted patients are learning a new implanted language. This applies to all CI patients, regardless of the manufacturer of implants. As world experience shows, completely new features that appear in an audible new speech signal after processing in the implant are sufficient for a CI patient to fully master his native speech.

Conclusion

Unlike normal subjects and hard-of-hearing patients, implanted patients do not have frequency analysis - they hear only certain frequency bands (each with its own) without spectral analysis, and the boundaries of the bands supplied to the processor microphone and the boundaries of the bands heard by the patient do not coincide. The threshold level of current perception is set during setup and should be at the processor trigger level. Otherwise, information is lost. After processing the instantaneous spectrum and transmitting stimuli to the electrodes, there is an increasing time delay in the perception of bands - from high to low. This delay varies significantly between CI patients and normal patients. If we consider the result of converting speech in CI, then we can say that the speech heard by the CI patient has nothing in common (similar) with the speech signal that a normal listener hears.

Given such a significant transformation of the amplitude-frequency-time characteristics of the speech signal in the implant, you should not tell CI parents that after the fitting their child will have the first degree of hearing loss. There is no question of bringing the auditory perception of implanted patients closer to natural hearing. In the case of use a hearing aid (HA) at the second ear, it should not be said that the HA will be configured in the same way as a cochlear implant, since all the described differences in auditory perception between normal subjects and CI patients persist in deaf patients.

Despite such a significant transformation of the speech signal and the resulting natural loss of the original speech information, CI patients are learning a new impoverished implanted language and in order not to impoverish it even more, the correct fitting of the speech processor is necessary. Many parameters determine the speech pattern perceived by patients - everyone has a different one -but in any case, the final processor setup involves setting such stimulation levels (maximum comfort, threshold levels, frequency range and so on) at which the patient receives the maximum possible acoustic information [15]. Only in this case will the rehabilitation result be the best possible, and the result of comparing different programs will be reliable.

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