

Recruitment in Cochlear Implanted Patients

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Abstract

Even at the initial stage of work on the topic of cochlear implantation, we had an assumption that after the operation of cochlear implantation (CI), CI patients may have the recruitment phenomenon. Taking into account the results of the world's first study of the stapedial reflex to sound stimuli in subjects after CI [1], we examined the results of patients with sensorineural hearing loss (SNHL) of peripheral type obtained under similar conditions of stimulation-registration. In both groups of patients, similar patterns of results are observed, which serves as an indication of the presence of recruitment in CI patients. The recruitment mechanism, proposed by us earlier in patients with peripheral type SNHL [2], is discussed in this study in CI patients.

Keywords: Cochlear implant; sensorineural hearing loss; stapedial reflex; sound stimuli; loudness; recruitment

Introduction

Even at the initial stage of work on the topic of cochlear implantation, we had an assumption that after the operation of cochlear implantation (CI), CI patients may have the phenomenon of accelerated loudness increase — recruitment. This is due to the fact that candidates for CI surgery are patients with a high degree of sensorineural hearing loss (SNHL). It is impossible to identify recruitment in them by psychoacoustic methods. But after the CI operation, they begin to hear threshold sounds at the level of 40 dB SPL and sounds with a 106 dB SPL at the threshold level of discomfort. Taking into account the results of the world's first study of the stapedial reflex to sound stimuli in subjects after CI [1], we reviewed the results obtained in patients with peripheral SNHL of the first degree under similar conditions of stimulation-registration.

For a more transparent consideration of the proposed topic, it is necessary to identify some reference points to build our presentation. In the following discus-

sion, we will rely on the results of the registration of the stapedial reflex in CI patients on acoustic stimuli with a frequency of 1123 Hz, presented by us earlier [1]. 1123 Hz is the central frequency of the sixth channel of the CI, chosen for this article for the reasons that normally in the region of this frequency, the signal intensity measured in dB SPL is quantitatively equal to the loudness expressed in the phons [3], which simplifies the presentation of the material.

A few words about the processing of the intensity levels of acoustic stimuli in a cochlear implant. All implants process the sound signal in a certain range of intensity. This dynamic range of sound has lower and upper borders. The lower limit is the trigger level of the processor. The trigger level is a SPL of input signal at which an electrical stimulus is generated with an amplitude recorded in the processor program as a threshold level. In most implants, the trigger level is located in the 40 dB SPL region. The upper limits

of different Firms are different ones (up to 118 dB in Neuro). In Med-El, it is equal to 106 dB SPL, i.e. the Med-El implant processes the input signal in the range of 40-106 dB SPL.

Consider the ideal case. Let's assume that with an optimal processor fitting the patient perceives sound at the threshold of audibility with an input signal of 40 dB SPL. With an input signal with an intensity level of 106 dB SPL, the patient perceives sound at the threshold of discomfort with a loudness level equal to 106 phons. Thus, the processed dynamic range of the input acoustic signal is 66 dB, and the range of perception in loudness is from 0 phons (audibil-

Table 1: The frequency of stimulation (Hz), the range of the reflex threshold (dB SPL), the average threshold level (dB SPL) and the relative threshold levels of the reflex (dB).

Frequency	Range	Average value of reflex threshold	Relative reflex threshold
1123	81-97	88.4±5.4	41,8 - 50,7

- a) With an input signal with a 40 dB SPL, the patient hears a sound of threshold intensity and, consequently, his hearing loss is 40 dB.
- b) The electrical maximum comfort level (MCL) is set so that when an input signal with a 106 dB SPL is received, the patient hears loud sounds at the threshold level of discomfort with a loudness level of 106 phons.
- c) Individual values of sound pressure levels at which threshold reflexes are recorded are in the range of 81-97 dB SPL. These results coincide with the results obtained in subjects with normal hearing [4,5].
- d) As can be seen by an increase of the reflex amplitude with an increase of the intensity of stimuli the loudness of input stimuli increases linearly from the threshold levels of the reflex to the intensity of 106 dB SPL [1], as is observed in normal subjects and in patients with SNHL [6,7].
- e) The relative threshold of the stapedial reflex, i.e. the magnitude of exceeding the threshold level of the stapedial reflexes above the threshold of hearing in CI patients (40 dB SPL) are in the range from 41.8 to 50.7 dB. Similar results are observed in patients with SNHL of peripheral type [8].

From the above comparison of the results of implanted patients (Table 1) and the results of patients with peripheral sensorineural hearing loss of the first degree, it follows that with a similar set of values of hearing thresholds, discomfort thresholds and stimulation parameters there is a great similarity in the results of the registration of the stapedial reflex in these two groups. Such results of reflexometry in patients with SNHL indicate that they have the phenomenon of recruitment [9], the essence of which is that with equal changes in the level of stimulation, the loudness on the affected side increases faster than on the side with normal hearing. In implanted patients, 66 dB of sound intensity are also distributed in 106 phons of loudness, the relative reflex thresholds are the same in two groups of subjects and taking into account the fact that hearing loss in implanted patients and patients with sensorineural

ity threshold) to 106 phons (discomfort threshold). I.e. the dynamic range of the input signal equal to 66 dB is converted into a dynamic range of perception equal to 120 phons, This already serves as an indication of the presence of recruitment in implanted patients. So. Let's consider parameters of stimulation, characteristics of the perception of the sound signal and the results of the registration of the stapedial reflex we have in a CI patient. For clarity, Table 1 shows the results of registration of the stapedial reflex in CI patients to a tonal stimulus of 1123 Hz, which we obtained earlier [1].

Table 1: The frequency of stimulation (Hz), the range of the reflex threshold (dB SPL), the average threshold level (dB SPL) and the relative threshold levels of the reflex (dB).

hearing loss have the same nature, we can conclude that patients after cochlear implantation, as well as in patients with SNHL have a phenomenon of recruitment.

Previously, we proposed an explanation of the recruitment mechanism in patients with SNHL of peripheral type [2]. We assumed that the mechanism of this phenomenon is explained by the processes occurring in the fibers of the auditory nerve. Mediators from internal hair cells change the permeability of the membrane of the fibers of the auditory nerve, resulting in an exciting postsynaptic potential (EPP) that initiates the occurrence of action potentials in the fiber of the auditory nerve, then entering the central nervous system. The dynamic range of single fibers of the auditory nerve is 20-50 dB [10,11], and the transmission of the entire audible range of sound pressure is explained by the fact that as the intensity of the sound signal increases, fibers with increasingly high thresholds of response are connected to the transmission of information [2]. Since the perception of sound in CI patients begins directly from the fibers of the auditory nerve, electrical impulses from the implant electrodes act as triggering stimuli, which also change the potential of the dendrites of the auditory fibers, which initiates the occurrence of informative spikes. The dynamic current range of a single fiber reaches 10 dB [12,13].

In patients with sensorineural hearing loss, EPP increases with an increase in the intensity of stimulation and high-threshold fibers are connected to the transmission of information [14]. A similar pattern can be assumed in implanted patients with an increase in the amplitude of pulses from the implant electrodes, fibers with higher threshold are also included in the work, which provides the entire dynamic range of current perception by implanted patients - up to 20 dB. Thus, it is possible to explain the mechanism of recruitment in CI patients, which manifests itself in them after surgery. These arguments are applicable to any frequency range, but they should be used taking into account the ratio of intensity and loudness levels in a given frequency band, i.e. dBs and phons, which differ in different spectral zones.

As it is known, individual threshold levels of the stapedial reflex to sound are normally located in a certain range of intensity [4,5]. But in subjects with normal hearing, the loudness is determined by the actual intensity, i.e. 106 dB SPL at a frequency of 1000 Hz is equal to loudness 106 phons. The situation is different for CI patients - they determine for themselves the maximum amplitude of electrical stimuli in each channel. They evaluate these signals as a threshold level of discomfort, i.e. the maximum comfortable loudness level which they will hear with an input signal of 106 dB SPL.

Since the threshold level of discomfort is a subjective category [15], patients themselves evaluate the loudness of maximum electrical stimulation (with an input signal of 106 dB SPL) and set the threshold of discomfort at their own discretion, i.e. not necessarily at the loudness level of 106 phons, but lower or higher. Naturally, the threshold levels of the reflex to sound will also change. If the patient sets the MCL by current so that with an input signal of 106 dB of SPL, he will hear, for example, 116 phons, then the threshold of the reflex to sound will be lower compared to the ideal patient described by us. If the patient sets the MCL by current so that with an input signal of 106 dB SPL, he will hear, for example, 96 phons, then the threshold of the reflex to sound will be higher compared to the ideal patient described by us. Under the condition of the normal condition of the middle ear and the reflex arc, the threshold SPL of the stapedial reflex to sound in CI patients depends on the position of the threshold reflex level of this patient within the normal range of threshold reflex levels (from the minimum - 70 dB SPL to the maximum - 100 dB SPL [4] and on the maximum value of the current subjectively set in the channel, which he evaluates (in one's own ear) evaluates as a MCL of loudness.

Based on the presented results, it is possible to consider the programs used by the patient as everyday work - programs selected in accordance with our instructions [16]. As a rule, when creating a configuration (4 programs recorded in the processor), the first program is created in the area of the threshold values of the stapedial reflex. Our study of the reflex to sound stimuli was carried out on the work program chosen by the parents — the second, third or fourth. The choice of the program demonstrates different excesses of the MCL of loudness over the reflex threshold levels. It should be noted that with categorical scaling of the loudness (CLS) [17], different subjects gave an assessment of the loudness of current levels in the area of the reflex threshold as "loud" or "good". By reflexes to sound, the child's choice of a work program can be explained. If the reflex threshold is low according to the SPL – the loudness rating at CLS is "good", then they choose the working program as third or fourth in configuration. And if the threshold level of the reflex according to the SPL is high - the assessment of the loudness at CLS is "loud", then the program 1-2. Therefore, it is necessary to take into account the subjective setting of the current level, which patients assess as a threshold of discomfort in SPL units. This issue requires additional research.

As an illustration, consider the extreme values of the reflex threshold. The threshold value of 73 dB SPL can be obtained for

two reasons: either this is the minimum value in the range of normal threshold reflex values (70-100 dB SPL), or the MCL level is set at a loudness of more than 106 phons. The joint manifestation of two causes is also possible. When considering the threshold at 97 dB SPL, it can also be at the normal upper limit of the range of reflex threshold values, or in this channel the MCL level is set at a loudness of less than 106 phons. It would be ideal to conduct the Fowler test (Fowler, 1937) in CI patients with normal hearing on one side and an implant on the other, but, unfortunately, we do not have such an opportunity.

If we look at all our results of reflex thresholds in CI patients [1], then out of 24 registrations, only in two cases the reflex threshold levels (97 and 106 dB SPL) are close to the most comfortable SPL (106 dB), in the rest they are lower, and in different patients by different current values. These results once again confirm the position that reflex threshold levels cannot be used as MCL levels of the optimal – working - program.

A similar pattern of

- Dispersion of threshold reflex levels,
- Relative reflex thresholds are lower than normal, and
- A linear increase in the amplitude of reflexes from threshold values to maximum values at 106 SPL is observed in the other channels.

Therefore, recruitment is also available there, but it should be remembered that the ratio of the SPL in dB and the loudness levels in phons differs from the zone of middle frequencies. Based on the discussion of results of the study of the stapedial reflex to acoustic stimuli in implanted patients [1], it can be concluded that they have the phenomenon of accelerated loudness increase - recruitment. The degree of recruitment depends on the position of the threshold reflex level of this patient within the normal range of thresholds (70-100 dB SPL) and on the maximum value of the loudness, which the patient subjectively evaluates as the maximum comfortable loudness level.

Conclusions

- The phenomenon of recruitment is detected in patients after cochlear implantation surgery, the mechanism of which is embedded in the fibers of the auditory nerve.
- The entire range of current perception from the threshold of audibility to the threshold of discomfort (up to 20 dB) is provided by the fibers of the auditory nerve with different thresholds of operation.
- One of the factors determining the value of the threshold SPL of the stapedial reflex to sound in CI patients is the maximum current level subjectively set in the channel, which the patient evaluates as MCL levels in phons.

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