LUPINE PUBLISHERS

ISSN: 2641-1709

Scholarly Journal of Otolaryngology

DOI: 10.32474/SJO.2023.10.000330

Research Article

Comparison of Cochlear Implant Models with Different Frequency Ranges

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Received: June 08, 2023 **Published:** June 20, 2023

Abstract

The processed frequency range of the acoustical signal in a Med-El cochlear implants can be set from the lower limit — 70-350 Hz to the upper limit — 3500-8500 Hz. Taking into account how the speech signal is processed in the cochlear implant processor, we assumed that there is the best frequency range for speech perception of implanted patients. Of the four 5-channel implant models with different frequency ranges: 350-6500, 250-6500, 250-8500 and 70-8500 Hz, the best word recognition result was found in the frequency range of 250-6500 Hz, the minimum recognition was in the widest frequency range [1]. It is necessary to narrow the search range of the boundaries of the optimal frequency range. The purpose of this study is to measure the intelligibility of spectrally deprived speech depending on the width of the frequency range in the narrower limits of the frequency ranges: 150-6500 Hz, 200-6500 Hz, 200-7000 Hz and 250-6500 Hz. The best recognition result of processed words was obtained in the frequency range of 200-6500 Hz.

Keywords: Cochlear implantation; CI model; frequency range; comb filtration; tonotopy; spectrally deprived speech

Introduction

The processed frequency range (FR) in a Med-El cochlear implant (CI) can be set from the lower limit of 70-350 Hz to the upper limit of 3500-8500 Hz. Taking into account how the speech signal is perceived by CI patients after its processing in the CI processor, it was logical to assume that there is the best frequency range for speech perception. To determine the best range, we need to compare the implants with different frequency ranges. Previously, we found that there are parallels between the perception of speech by implanted patients and the perception of spectrally deprived speech, i.e. a speech signal with mosaic-deleted sections of the spectrum by subjects with normal hearing [2]. Based on these parallels, we conducted a model study of speech perception in four frequency ranges of CI: 350-6500, 250-6500, 250-8500 and 70-8500 Hz [1]. The highest intelligibility of words was obtained in the fre quency range of 250-6500 Hz. The intelligibility of words decreases with an increase in the low-frequency boundary of the frequency range 250-6500 Hz to 350 Hz, as well as with the expansion of the FR in the direction of high frequencies up to 8500 Hz and with the expansion of the FR 250-8500 Hz in the direction of low frequencies up to 70 Hz. We discussed these results [3] and on this basis concluded that the optimal frequency range should be sought in the vicinity of the 250-6500 Hz range. Such investigation was carried out in this study.

Methodology

Standard Greenberg-Zinder lists of words for speech audiometry (30 words each) were used as the initial test material. We used four frequency ranges of CI in the models: 150-6500 Hz, 200-6500 Hz, 200-7000 Hz and 250-6500 Hz. In the Maestro program, we set these frequency ranges for 12-channel implants and recorded the values of the central frequencies of the first and twelfth channels of four implants. These values were used as the central frequencies

of the first and fifth channels of our models of 5-channel implants. Further, according to the formula from study of W. Hartmann [4], the values of three frequencies were calculated so that the coordinates of the peaks of the oscillations of the basilar membrane corresponding to these three frequencies and the central frequencies of the first and 12th channels of the 12-channel implant in each frequency range were equidistant from each other. The distribution of these frequencies equidistant along the basilar membrane is in accordance with the normal tonotopic organization of the cochlea. We chose this distances by analogy with the equal distances between the electrodes in the implant electrode chain.

Spectral processing of lists of words was carried out using the comb filtering program "LOR" [5]. The comb filtering process involves dividing the speech signal into spectral bands of different width that can be mosaically removed by the experimenter. As a result of the processing, speech signals were obtained, in which a five 50 Hz bands remained from the full speech spectrum. The central frequencies of these bands were equal to the five frequencies we calculated in each of the four frequency bands. Taking into account the sufficiently high intelligibility of speech in the 250-6500 Hz band obtained in the previous work [1], in order to reduce the informative value of the speech signal, we carried out double comb filtering. After the "insertion" of such «5-electrode chains" into the cochlea, the central frequencies in the four implant models will be at equal distances from each other in accordance with the normal tonotopy of the cochlea. Table 1 shows five frequency values in four frequency ranges, which are located at the equal distance from each other along the basilar membrane. (Table 1) The values of five frequencies that are equidistant along the basilar membrane in accordance with the normal cochlear tonotopy in the four frequency ranges used in our study in each of the CI model. As an example, the following Figure 1 shows a spectrogram of one of the used speech signal. 7 adult subjects aged 35 to 63 years participated in this study. They have normal hearing. We did not consider gender, age, etc. All the subjects participated in speech research for the first time. After setting a comfortable loudness level, the subject had to recognize the processed words. Correct answers were registered. «Sennheiser» headsets were used.

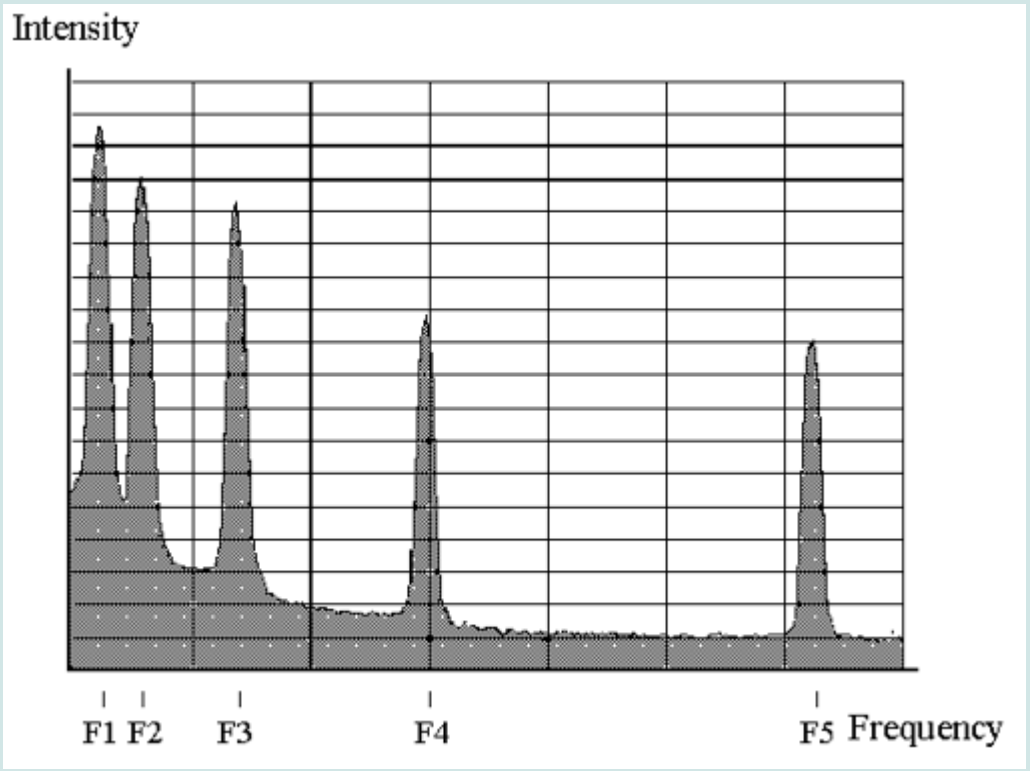

Figure 1: A real spectrogram of one of the used speech signal.

Table 1

Frequency ranges (Hz)	Central frequency of 1-st channel of 12-channel CI	2-nd frequency of 5-channel CI model	3-rd frequency of 5-channel CI model	4-th frequency of 5-channel CI model	Central frequency of 12-th channel of 12-channel CI
150-6500	193	555	1285	2757	5723
200-6500	241	626	1379	2847	5725
200-7000	241	642	1439	3023	6149
250-6500	289	695	1468	2936	5727

Table 2

Frequency range, Hz	150-6500	200-6500	200-7000	250-6500
Recognition of words, %	38	53	47	48

Results of Research and their Discussion

The averaged results of measurements of recognition of spectrally deprived words depending on the width of the frequency range of the CI model are presented in Table 2. Averaged results of measurements of intelligibility of spectrally deprived words depending on the width of the frequency range (Hz) of the cochlear implant model. As we expected, the differences in the intelligibility of words in the FRs, which are not very different from each other, turned out to be less pronounced than in the previous work [1]. For this reason, we will not be able to assess the reliability of the differences, but only to determine the trend. As can be seen from the presented results, the best of the four frequency ranges for the perception of a spectrally deprived speech signal is the frequency range from 200 to 6500 Hz. A noticeable decrease in the intelligibility of words is noted when the FR 200-6500 Hz is expanded towards low frequencies up to 150 Hz. We assume that the 200-250 Hz frequency band contains more speech information than the 150-200 Hz band. This is due to a decrease in the amount of information contained in more and more low-frequency bands of the speech spectrum [6].

An increase of the FR of 200-6500 Hz by 500 Hz towards the high frequency to 7000 leads to a decrease in speech intelligibility. We assume that this is mainly due to a decrease in the information value of the fifth high-frequency band of the CI model with a FR of 200-7000 Hz. As for the possible decrease in the intelligibility of words in CI patients at FR 200-7000 Hz, this may be due to a decrease in the information content of the high frequency band, as well as a decrease in the channel selectivity of stimulation (CSS), which we discussed earlier [3]. It is interesting to note that similar values of speech intelligibility were obtained with a FR of 200-7000 Hz and 250-6500 Hz. We assume that due to the expansion of the FR of 250-6500 Hz towards the low frequency to 200 Hz there is an increase of word intelligibility, but with an increase of the upper limit of the FR of 200-6500 Hz by 500 Hz, there is a decrease in speech intelligibility for the reason discussed above. Moreover, speech intelligibility improves and decreases equally, which determines the close results at FR 200-7000 Hz and 250-6500 Hz. The discussion of the results indicates in favor of setting the lower limit of FR at a frequency of around 200 Hz. Setting the upper bound requires further investigation. It should be noted the variation in the values of speech intelligibility with the same FR in different subjects. If we look at the individual results of the subjects at FR 200-6500, then the intelligibility of the words of individual subjects in ascending order of the results of intelligibility looks like this: 23, 47, 47, 50, 53, 67 and 83%. The difference between the maximum and minimum results is more than three times. N.B. In our previous study [1] the difference between the maximum and minimum results is less than two times. This difference is due to the difference between the groups of participants.

This variation serves as a vivid illustration of the different abilities of different people to master a new sound picture of speech. Here we can draw an analogy with CI patients. Similar differences were discussed in a previous papers [1,7,8]. It is interesting to compare the mean results of two measurements of speech intelligibility in two groups of subjects at the same FR - 250-6500 Hz. The average values of speech intelligibility in these studies differ. In the first, the intelligibility of words is 73% [1], in the present – 53%. We explain this difference by two reasons. Firstly, in the first group, the age of the subjects is 20-31 years, in the second - 35-63 years. Secondly, in order to reduce the amount of information in the test words, we conducted a double comb filtration. As we have already said, the main thing for us is not the maximal average values of speech intelligibility of groups, but a comparison of the values of speech intelligibility obtained with different stimulation parameters. There are some details that should be taken into account when considering the results we have obtained.

a. In our model, real speech bands of 50 Hz width are perceived by the subjects in accordance with normal tonotopy. As for implanted patients their tonotopy is determined by the position of the electrodes' chain in the scala tympani, the size of cochlea, the length of electrode chain (Cochlear!), the current dissection between pairs of electrodes and a frequency range. Obviously, every CI patient will have his own new tonotopy. A striking example of this statement is the Nucleus, in which a chain of electrodes is inserted into half of the cochlea length and the upper limit of the FR can be set to 10 kHz. I think that the narrower frequency range the better speech perception in noise. I have some considerations for comparison of different CI programs in one CI patient.

b. Lists of words used by us are recorded in a male voice. It is possible that women's voice will be better perceived in another FR.

c. The speech signal spectra differ in different languages, but I think that in European languages it is insignificant, so the best FR will be the same in these countries.

It is interesting to note that in our practical work we used FRs that were close to optimal ones according to the results of our model studies, long before conducting our research on modeling CI with different FR. So when we first connected to CI, we set a FR of 250-6500 Hz in the 12-channel CI. And in the MIMIC program, which was patented in 2006 [7], we use a FR of 200-6250 Hz. It should be noted that in the first 8-channel CI, FR of 300-5500 Hz was used. As follows from the conducted research, our method of speech in-

telligibility measurement successfully works on the CI model with different frequency ranges [1]. It can also be used in CI patients to compare speech intelligibility in different programs, for example, with different FR, strategies, etc. To do this, you need to create special lists of test words. I think that this is not a complicated procedure for programmers of any CI Company. After some training of the implanted patient a reliable comparison of different programs will take 15-20 minutes. Based on the results of a model study conducted on the basis of parallels between the perception of speech by implanted patients and the perception of a spectrally deprived speech by subjects with normal hearing, it can be concluded that from a model comparison of four frequency ranges conducted in this study, the best FR of the CI model is 200-6500 Hz. It should be noted that this is not the final result for setting the optimal frequency range in CI patients. In the process of work, there were considerations that in order to improve the perception of speech by implanted patients, some spectral transformations of the speech signal can be made in the CI program, which also requires verification using our method of comparative study of speech intelligibility. We also had the consideration that the narrower the frequency range, the better the perception of speech in noise.

Conclusions

a) The maximal intelligibility of words was found in the frequency range from 200 to 6500 Hz when comparing the CI models using a spectrally deprived speech signal represented by 5 bands of 50 Hz width in four frequency ranges.

b) After some modifications our method of measurement of speech intelligibility can be used to compare various acoustic signal processing strategies in the speech processor of a cochlear implant.

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DOI: 10.32474/SJO.2023.10.000330