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EFFECT OF THE MASTOID CAVITY AND EXTERNAL AUDITORY CANAL VOLUME CHANGES IN SOUND TRANSMISSION

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The main function of the middle ear is well-known. It serves as a mechanical transformer, designed for transmission of acoustic energy from the external air to the cochlea fluids. In the absence of such energy transformer of the vibrational motion of air particles will be reflected at the on the border with the labyrinth fluid. The appearance of the corresponding mechanical amplification leads to increase pressure and transfer of sound energy is lossless.

In the literature there is a discussion about the factors affecting the transmission of sound in the middle ear. Otosurgeons often do not pay enough attention to the value of the resonance in the cavities of the middle ear and external auditory canal (EAC) in the planning of surgical intervention However, middle ear surgery in some degree alters the volume of these cavities, which could have a significant impact on the sound transmission by middle ear and, ultimately, on perception of hearing thresholds. The acoustic effect of changes in the volume of the cavities in different types of tympanoplasty is difficult to define clinically, since such surgery is performed while the restoration of the tympanic membrane and ossicular chain continuity also made. The combination of these stages of an operation does not allow it in the end determine the effect of only one change in the volume of the cavities of the middle ear and EAC.

To the most significant anatomical changes in the middle ear leads three most common operations-canal wall down tympanoplasty (CWD), canal wall up tympanoplasty (CWU) and tympanoplasty with mastoid obliteration (MO). At the first intervention (CWD) posterior wall of the EAC is removed, aditus, antrum and mastoid's cells are opened into the EAC. As a result the pneumatic cavity in the middle ear is represented only by the tympanic cavity and Eustachian tube and the EAC, combined with the mastoid, represent a large bowl in front of the eardrum (fig 1).
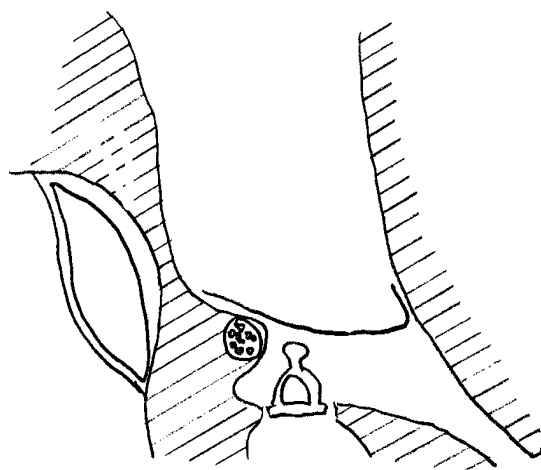

Fig. 1. Schema of the canal wall down (CWD) tympanoplasty. In front the tympanic membrane has a big cavity witch includes EAC and mastoid. Tympanic membrane fixed on the ossicular chain and medial attic wall. Air space in the middle ear includes Eustachian tube and tympanic cavity.

In the CWU tympanoplasty the middle ear space is enlarged during the mastoidectomy with posterior canal wall preservation, and communication between mastoid and tympanic cavity is enlarged as a result of the posterior tympanotomy. The result of this operation is to increase the volume of pneumatic cavities of the middle ear and the creation of a wide communication between the mastoid and tym-

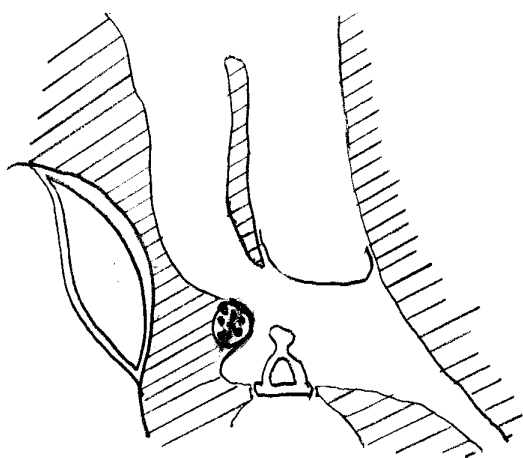panic cavity, keeping the anatomy of the EAC intact (fig 2).

Fig. 2. Schema of the canal wall up (CWU) tympanoplasty. EAC has a normal anatomy. Tympanic membrane is in the normal position. Air cavity in the middle ear includes Eustachian tube, tympanic cavity and mastoid.

The tympanoplasty with MO leads to fill the mastoid cavity by plastic materials and restoration of EAC configuration. In such a way pneumatic cavities of the middle ear space is represented by the tympanic compartment and Eustachian tube, and the shape of the EAC approaches to its normal form (fig 3).
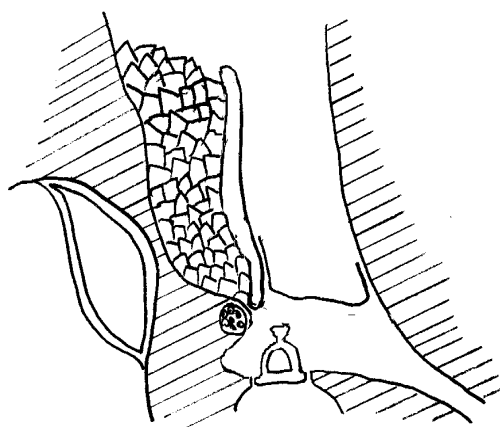

Fig. 3. Schema of the tympanoplasty with mastoid obliteration (MO). EAC has a normal anatomy. Tympanic membrane is in the normal position. Air cavity in the middle ear includes Eustachian tube and tympanic cavity.

We have studied the acoustic effect of these tree types of changes in the volume of the cavity of the middle ear and EAC in an experiment on an isolated block of the cadaveric temporal bones.

Materials and methods

We used 5 human temporal bones, which were prepared with the preservation of the mastoid air cells, and the squama of the temporal and occipitalbones without the auricle and external part of the cartilaginous EAC. Cadaveric temporal bone is harvested during the first 24 hours after death. Bones examined for the absence of ear pathology and stored in 70 % ethanol solution at 5 ^{0}C.

For this study we used an acoustic chain, described by T. Dumon et al. (1995). The amount of energy of acoustic waves transmitted by cochlea's liquid was evaluated using a hydrophone type 8103 firms "Bruel & Kjaer" (Denmark) (Fig. 4). We drilled a hole with the 2 mm bur in the basal turn of cochlear by using middle cranial fossa approach. The basal turn is located anterior to the labyrinthine portion of the facial nerve. Metallic cone was introduced in the hole. The edge between the cone and bone wassealed by bone cement. Cochlea and the cone were filled with saline solution. In the metal cone-mounted hydrophone, the signal from which passes through a filter type 1621 and type 2635 preamplifier firms "Bruel & Kjaer", and then recorded using an two-channel oscilloscope "Tektronix TDS 320" (USA).
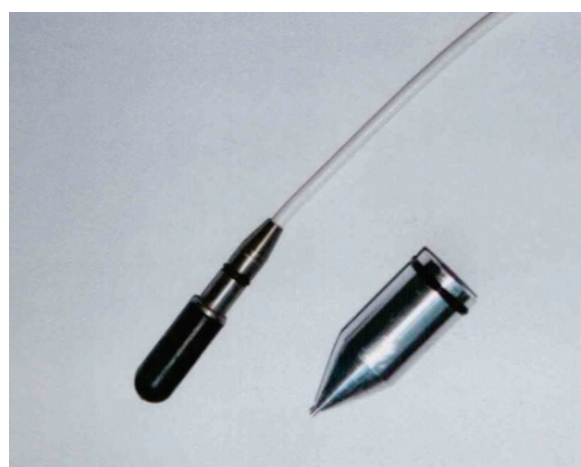

Fig. 4. Hydrophone type 8103 firms "Bruel & Kjaer" (Denmark) and cone.

Sound was supplied into the ear canal through the ear speculum, rigidly fixed on the speaker "Telephonics TDH-39 P" (France). Ear speculum was not in contact with the wall of EAC. The signal frequency was varied from 200 to 4000 Hz using a generator HP 33120 A (USA) with a pitch of 100 Hz in the range of 200-2000 Hz and 200 Hz increments in the range 2000-4000 Hz. The sound pressure level in the EAC was maintained at a constant level of (81±0,5) dB andmonitored with an oscilloscope "Tektronix". Scheme of the experimental chain is shown on figure 5.
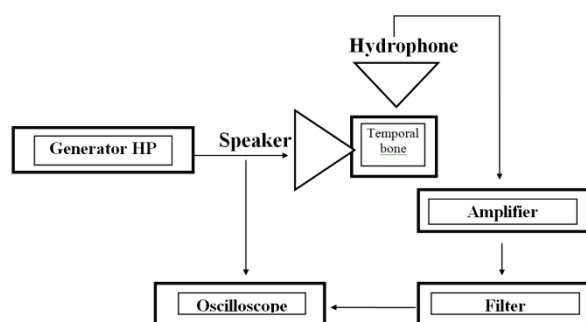

Fig. 5. Scheme of the experimental chain.

Temporal bone with a hydrophone and a cone, speaker with ear speculum rigidly fixed to the metal tripod (Fig. 6).
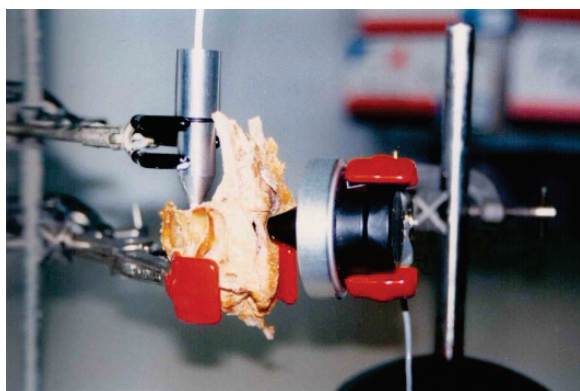

Fig. 6. Temporal bone with the cone, hydrophone and speaker.

Experimental chain was calibrated before each series of measurements. Preliminary studies have focused on the reproducibility and repeatability of tests. The maximum amplitude of the response changes when the sound source reinstalled was 25 mV. The corresponding measurements when reinstalling the cone of hydrophone gave the maximum change of 40 mV.

Measurements were performed in the following situations: 1) normal EAC and tympanic membrane in the intact temporal bone, 2) CWU tympanoplasty with posterior tympanotomy, performed without damage to the roof of mastoid cavity, wall of sigmoid sinus or the posterior wall of the EAC; cortical mastoid defectwas closed by periosteal flap and cotton soaked in saline solution before the measurement, and 3) CWD tympanoplasty, performed without damaging of the roof and walls of mastoid cavity and sigmoid sinus, and 4) tympanoplasty with MO with the reconstruction of posterior bony wall of EAC and filling the mastoid cavity with cotton balls soaked in saline solution. In all cases the ossicular chain and tympanic membrane remained intact. The volume of the EAC and mastoid cavity was measured in each temporal bone.

Results
1. Intact temporal bone. The transmits sound in the intact temporal bone was characterized by the presence of four resonance peaks at frequencies 700, 1400, 2400 and 2800 Hz (Fig. 7). The averaged amplitude of the responses on corresponding frequencies was 433,2; 306,7; 516,4 and 472,1 mV.
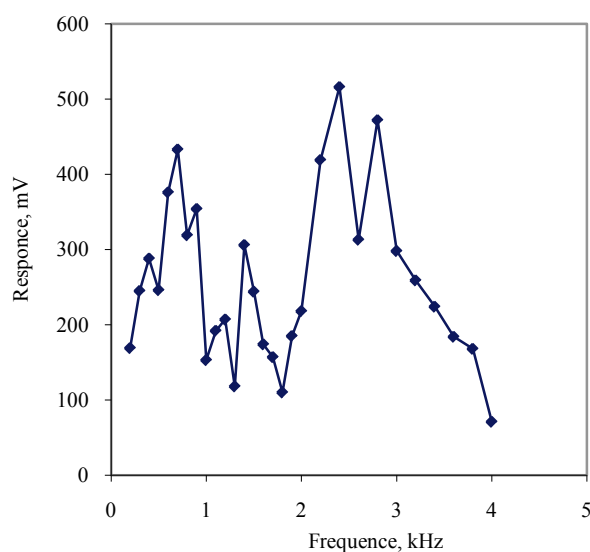

Fig. 7. Amplitudes of responses in the intact temporal bone.

The volume of the EAC in the intact temporal bone ranged from 0,8 to 1,0 cm^3, on average – 0,88 cm^3.

2. CWU tympanoplasty. In this model two evident resonance peaks were recorded at frequencies of 1500 and 2600 Hz (Fig. 8). The average amplitude of the response to the resonant frequencies was 741,1 and 926,5 mV. It is noteworthy that there are two resonance peaks and their amplitude is large compared to the intact bone, which can be explained by an increase in resonant mastoid cavity after opening the osseous partitions between the cells and their integration into a single cavity. Our suggestion was confirmed by the following observations.
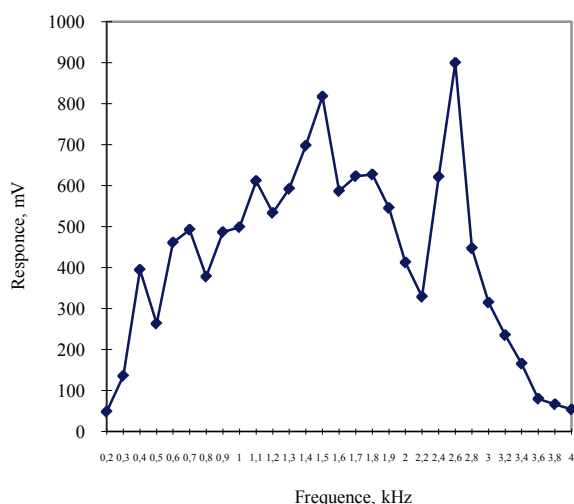

Fig. 8. Amplitudes of responses in the CWU tympanoplasty.

The volume of the mastoid cavity after the CWU was from 4,2 to 10,1 cm^3. Two bones had small cavities in the mastoid; the volume was 4,2 and 4,3 cm^3. Three others bones had extremely well-developed mastoid air cells, and its volume was 7,4; 8,3 and 10,1 cm^3. Thus, we can compare the results of studies with poorly and well-developed pneumatic system of the mastoid process (Fig. 9).

As seen from these figures, the best sounds transmission observed at medium frequencies (400 to 2200 Hz) with large cavities of the mastoid, compared with a small. This difference was statistically significant at the frequencies 600, 1000, 1400, 1500, 1700 and 1800 Hz (p<0,05).
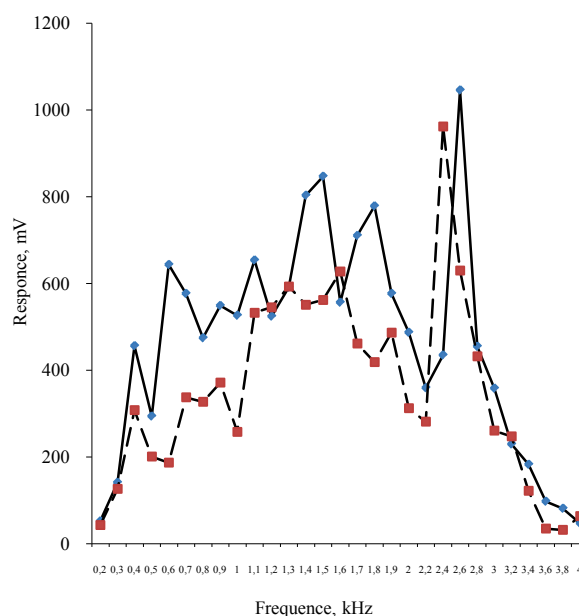
Fig. 9. Amplitudes of responses after CWU tympanoplasty in the different size of mastoid cavity.

3. CWD tympanoplasty. Two resonance peaks were registered in the model of CWD, but they were shifted to lower frequencies: a more marked at a frequency of 1200 Hz and less marked at a frequency of 1900 Hz (Fig. 10).
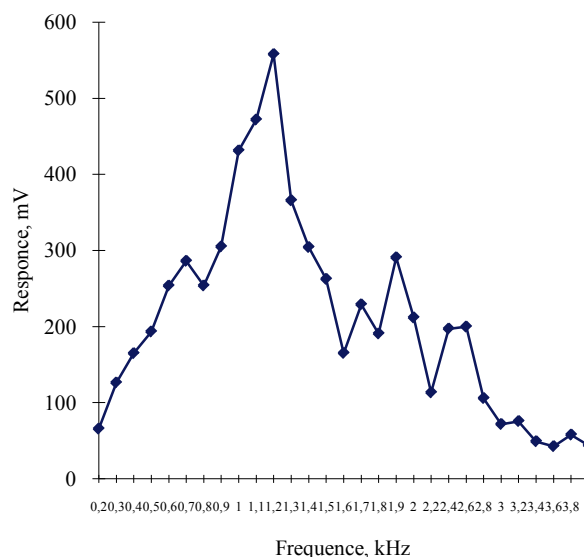
Fig. 10. Amplitudes of responses in the CWD tympanoplasty.

4. Tympanoplasty with MO. The shape of diagram and responses were similar to those recorded in the temporal bone after CWU (Fig. 11).
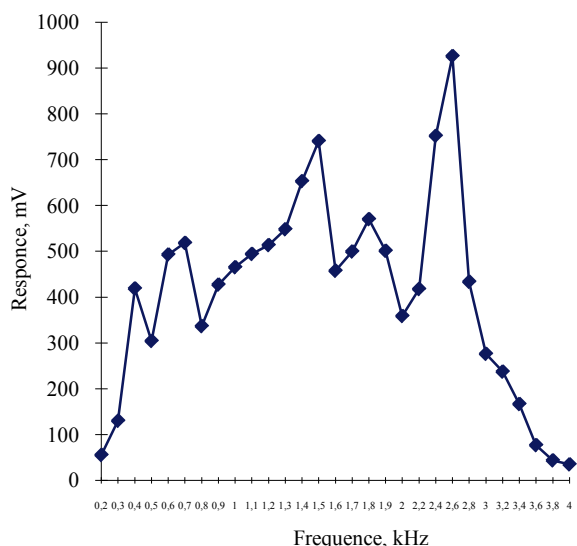
Fig. 11. Amplitudes of responses in the tympanoplasty with MO.

Two marked resonance peaks at frequencies of 1500 and 2600 Hz were registered (as well as after CWU). The average amplitude of the response at these frequencies was (741,1±0,4) mV and (926,5±0,3) mV.

CWU
CWD
MO
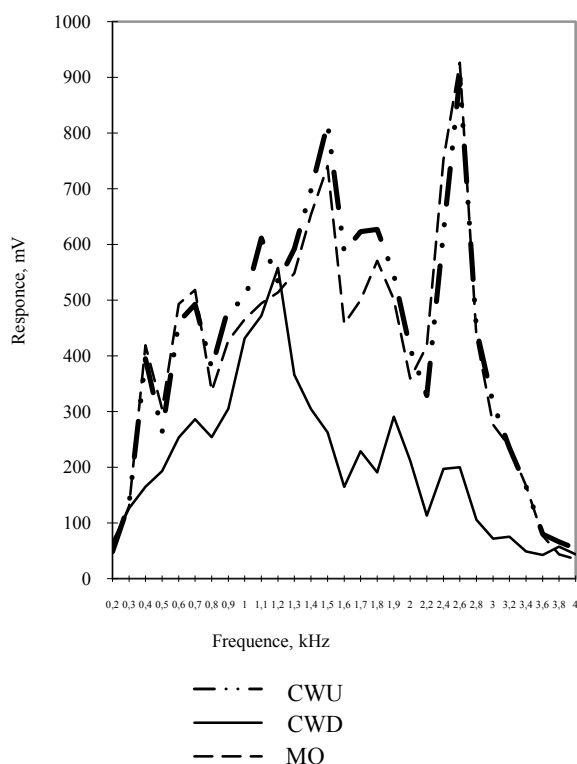
Fig. 12. Amplitudes of responses after CWU, CWD and tympanoplasty with MO.

Diagrams of the amplitudes of the responses received after CWU, CWD and MO are presented together in the fig. 12. As can be seen from the graphs, the amplitude of responses after CWU and MO is greater than after CWD for almost the entire frequency range studied, except 200 and 1200 Hz. Moreover, this difference is most significant in the range 1300-3400 Hz, which has a particularly important role in speech discrimination.

We can note a tendency to register higher amplitude response after CWU in the main speech frequencies than after MO. As seen from the diagrams, the amplitude of the response in the frequency range 800-2000 Hz is much higher in the temporal bone after CWU. This difference is statistically significant in the frequencies 1100, 1600 and 1700 Hz. A higher amplitude responses after MO was fixed in the frequency range 400-700 Hz and 2200-2600 was. It should be noted that this difference is statistically significant at frequencies 2200 and 2400 Hz.

Discussion

Using bone from human cadavers reasonably raises the question of post-mortem changes in them, and their influence on the difference between the results obtained in studies on isolated temporal bones, the mathematical model and the human ear. Onchi (1961), studying the impedance of the temporal bone, showed increased resistance at low frequencies, compared with living subjects, at frequencies exceeding 1 kHz, the differences are not noted. Post-mortem changes were also observed in the experiments on cats (Jako et al., 1966) and measuring the impedance of the temporal bone (Zwislocki, Feldman, 1963). The cause of these artifacts usually is drying up. The data obtained Zwislocki and Feldman, of course, confirmed the occurrence of negative pressure in the middle ear after death. We conducted a comparative study, comparing the effects of various surgical interventions on the same temporal bone, and tried to keep with the same conditions, maintaining the structure of the middle ear in a damp condition, reducing the likelihood of influence of artifacts in our experiments.

EAC in acoustic aspect is a tube closed by tympanic membrane, amplifying the sound

pressure at the eardrum for more than 20 dB at the resonance frequency as compared with the point at the entrance to the ear (Shaw, Teranishi, 1968; Goode et al., 1977; Browning, Gatehouse, 1984). The resonance peak is the fundamental frequency, the length of which is approximately four lengths of ear canal, and for the normal ear is in the range between 2 and 4 kHz (Djupesland, Zwislocki, 1973). In our experiment, the resonant peak of the ear canal ranged from 2,4 to 2,8 kHz. Interventions on the middle ear violate the anatomy of EAC, tympanic cavity and mastoid, changing their configuration and size, which leads to a shift of the acoustic characteristics. So, after a CWD tympanoplasty, we noted the disappearance of the resonance peak of the EAC.

The resonance peak of the middle ear, according to Kurokawa and Goode (1995), determined in the range of 0.9-1 kHz and has a large individual variability. In our experiments, it was in the range 0.7-0.9 kHz. The middle ear is a significant barrier to the transmission of sound from the eardrum to the cochlea. The degree of severity of the resistance (or hardness of the middle ear) is dependent on the frequency of sound. Thus, according to Dancer and Franke (1995), it is less expressed at low frequencies. Most of the sound wave energy is expended to overcome air resistance in the cavities of the middle ear, stiffness of the tympanic membrane and tympano-ossicular systemligaments.

Studies on cadaveric temporal bones (Gundersen, 1971; Tonndorf, Khanna, 1972) and living people (Von Bally, 1979; Lokberg et al., 1979) showed that the vibration of the ossicles in response to the constant sound pressure level is attenuated at frequencies above 2 kHz. Holographic study of the human tympanic membrane showed that the decomposition occurs to secondary vibrations of the eardrum to the small, slightly vibrating at high frequency areas. The acoustic effect of the middle ear is the attenuation at high frequencieshas not always a downward dependence. There is a notch at frequencies between 3 and 4 kHz with a very large individual variation in the frequencies above 1?5 kHz. In our experiments, we recorded the attenuation at frequencies above 3?2 kHz, and the acoustic notch was in the frequency of 1?8 kHz. Acoustic notch dis-

placed with the change in the volume of the cavities of the middle ear and EAC in modeling the different operation on the temporal bone blocks. Thus, when CWU and CWD it was noted in the frequency of 2.2 kHz, while MO the notch was in 2 kHz.

There is very limited information on the influence of the volume in the middle ear cavity and EAC changes on the sound transmission in humans. The volume of the tympanic cavity is on average 0.5 cm3, and the mastoid cavity – 8,6 cm^3 with a wide range of variation – from 2,1 to 17,44 cm^3 (Zwislocki, 1962). variations in cavity volume produce large effects in energy reflectance (Voss et al., 2008).

Effect of the volume changes of the cavities in the sound transmission can also be studied with an electronic analogue of the middle ear (Zwislocki, 1962; Shera, Zweig, 1991; Rosowski, 1991). Typically, the analog circuit is used at the input DC voltage, which corresponds to a constant sound pressure level at the eardrum. The output signal is a current through the cochlea portion of the chain, which reflects the movement of the stapes. If you change the conditions in that part of the chain, which simulates the middle ear cavity, we studied the effect aditus blockand expansion of the cavities on the middle ear sound transmission. On the basis of experiments on the mathematical model of the temporal bone revealed that the expansion of aditus and mastoid cavity (model CWU) leads to improved sound transmission at low frequencies in comparison with the model of the CWD. However, a better transmission in the most important range of frequencies from 1.5 to 4 kHz is in the cases with aditus blockage (model MO). Due to the fact that the study was carried out on a small number of temporal bones, and there was considerable individual variation in between, we can not draw any general conclusions. However, the aditus block, as is done during the MO, is most advantageous for frequencies 1,3-3,2 kHz with respect to the CWD. For low frequency (below 1.2 kHz), this difference is less evident.

A. Gusakov and V. Bereznyuk (1987) studied the effect of antromastoidal cavity on sound transmission in the cadaver temporal bones using a piezoelectric transducer mounted on the stapes. They found that after the CWD is a sound pressure level decrease in by 1-4 dB

in almost all the frequencies of the speech range, after CWU pressure on the base of the stapes is close to the normal, while at low frequencies even higher than it by 3 dB. Our data also suggest carrying out the worst sounds in the model of CWD than CWU and MO, and almost the entire frequency range, but particularlyevidently at the frequencies above 1,3 kHz. The formation of a large pneumatic cavity, as is the case with CWU leads to a significant increase in the amplitude of responses compared with the intact temporal bone. This may be due, in our opinion, especially with increasing resonance in the cavities of the middle ear after CWU. The increase in the amplitude of responses in the temporal bone after MO comparing with the intact temporal bone can be explained by increased "stiffness" of the middle ear pneumatic system by obliteration (elimination) the mastoid cells, antrum and aditus. Our results confirm the findings of V. Bereznyuk (1994), in the experimental study of the middle ear impedance was shown that the formation of a large antromastoidal cavity reduces the "rigidity" of the pneumatic system of the middle ear and makes it suppler, especially for low frequencies.

V. Shkorbotun (1988) notes the desirability and importance of forming a neotympanal cavity with maximum volume. Our data confirm that the wider mastoidectomy was made, the better conditions for the sound transmission is. We came to this conclusion by comparing the response curves of the amplitudes of the temporal bone with different volumes of the mastoid cavity. Thus, to improve sound transmission by middle ear it is necessary to perform a wide mastoidectomy and form the all pneumatic neotympanal cavity.

Goode and colleagues (1977) observed a decrease in the normal resonance peak and the appearance of antiresonance after surgical join between antrum and the EAC, as is the case with the CWD. According to Evans et al. (1989), the frequency of the resonance peak of the EAC after CWD tympanoplasty is reduced from 3,9 to 1,9 kHz, and produced a negative peak at a frequency of 4,2 kHz. Significant deviations from the physiological acoustic resonance curve of the normal EAC marked Chandler (1964) and Hartwein (1989) when resizing the external auditory meatus and the volume of surgical cavity. Increasing the size of the meatus made resonance peak shifts toward higher frequencies above the physiological norm, i.e. above 4 kHz, and an increase in volume of surgical cavity leads to a shift of the resonance peak to lower frequencies. Thus, by appropriate manipulations, such as increasing the size of the meatus and reducing the volume of surgical cavity can be achieved physiological acoustic resonance. McElveen et al. (1982) in experiments on isolated blocks of the temporal bone showed that the block of aditus (as is done with CWD) leads to a slight increase of sound transmission at frequencies of 1,5-4 kHz, and to decrease at frequencies below 1 kHz in comparison to aditus and mastoid cavity extension (as is the case with CWU).The experimental digital model showed improvement the sound transmission after the CWU on the whole frequency range. In the CWD, we noted much smaller amplitude responses compared to the amplitude response for CWU and MO, especially at frequencies above 1.3 kHz. This is primarily due to the exclusion of resonant effect of the EAC, which is most expressed in the range of 2-3 kHz. We observed a significant increase in the amplitude responses in cases of restoring the anatomy of the ear canal, and obliteration (exclusion) the pneumatic mastoid cavity (model tympanoplasty with MO).

Conclusion

Based on our study and analysis of literature data we can conclude that the pneumatic system of the middle ear and EAC played a major role in the sound transmission. In execution the CWU tympanoplasty mastoidectomy must be performed as widely as possible. The higher amplitude of the responses to the middle and high frequencies recorded in the CWU, which can serve as a theoretical prerequisite for the selection of this tympanoplasty technique in order to obtain better functional results. Tympanoplasty with MO gives more favourable functional results at lower frequencies compared with the CWU. In the implementation of CWD tympanoplasty should, in our view, seek to minimize the volume of mastoid cavity not only to facilitate post-operative care, but also to improve the acoustic effect.

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EFFECT OF THE VOLUME CHANGES OF MASTOID CAVITY AND EXTERNAL EAR CANAL ON SOUND TRANSMISSION

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Summary

The experiment on the fresh human temporal bone performed to evaluate the role of mastoid process pneumatic system in the sound transmission after different type of mastoid surgery. Amplitude responses were studied in the comparative aspect after the canal wall up (CWU) and canal wall down (CWD) tympanoplasty and mastoid obliteration (MO) surgery. Resonance picks were preserving on the 700 Hz frequency and had displacement on the 1500 and 2600 Hz frequencies after CWU and MO. Two resonances picks after CWD were: more expressive on the 1200 and less expressive on the 1900 Hz. Higher signal's amplitude was noted after MO in the whole diapason of examined frequencies in comparison with responses which were registered after CWD. Higher response's amplitude on the middle and high frequencies was observed after CWU than after MO, that may used as a theoretical background for choice of CWU to achieve the best functional results. The main goal of CWD procedure should be not only to reduce the volume of cavity for easy care of operated ear but also to get a maximum functional result.

ВЛИЯНИЕ ИЗМЕНЕНИЕ ОБЪМА ПОЛОСТИ СОСЦЕВИДНОГО ОТРОСТКА И НАРУЖНОГО СЛУХОВОГО ПРОХОДА НА ПЕРЕДАЧУ ЗВУКА

Борисенко О. (Киев)

Резюме

Проведено экспериментальное исследование на свежих трупных височных костях человека для оценки влияния пневматической системы сосцевидного отростка на проведение звука при моделировании трех различных типов тимпаномастоидопластики. Стимуляцию производили в диапазоне частот 200-4000 Гц. Проведено сравнение амплитуды ответов зарегистрированного сигнала после закрытого (ЗТ) и открытого (ОТ) варианта тимпанопластики, а также после мастоидопластики (МП). Более высокие амплитуды ответов были получены после МП во всем диапазоне частот по сравнению с ОТ. Более высокие амплитуды ответов на средних и высоких частотах были зарегистрированы при моделировании ЗТ и МП, что может служить теоретической предпосылкой для выбора этих методов тимпанопластики как наиболее эффективных в плане восстановления слуха. При проведении ОТ следует стремиться уменьшать объем операционной полости за счет ее облитерации не только для облегчения послеоперационного ухода, но и для получения максимального функционального результата.