EFFECT OF SURGICAL DRILLING ON COCHLEAR POTENTIALS

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The aim of the experiment was to examine the effect of noise and mechanical vibrations generated during the drilling of the bones surrounding the cochlea on the cochlear microphonics (CM). The experiment was carried out on a group of 40 guinea pigs divided equally into a group to be studied and a control group. In the studied group, CM values were measured three times: immediately after opening the bulla, after 30 minutes of nonstop drilling and two hours later, whereas in the control group they were measured twice: immediately after opening the bulla and 2.5 hours later. In this way the post-drilling shock and the long-term injuries to the cochlea could be studied. A statistical analysis of the obtained results shows that surgical drilling may cause an average decrease of 50–60% in CM values in comparison with the control group.

Key words: cochlear microphonics, guinea pigs, surgical drilling.

1. Introduction

When the drill was introduced into ear surgery, the question of the safety of its use arose. The results of many experimental examinations and clinical observations show that exposure to noise (acoustic energy) generated during the drilling of bones may cause damage to hearing, particularly in the case of long exposure to high levels of acoustic energy transmitted through the air and through the vibrations of the bone surrounding the cochlea [4–6, 9–11]. The damage to hearing may be temporary or permanent (as a result of irreversible changes in the cochlea) [12].

The effect of surgical drilling on the experimental animals' cochlea was studied. The goal was to assess the possibility of damaging the inner ear during the non-stop drilling (for 30 minutes) of the bones surrounding the guinea pig's cochlea. The experimental drilling time of 30 minutes corresponds to the average total drilling time in a typical inner ear operation.

2. Materials and method

The experiment was performed on 45 multicoloured guinea pigs of both sexes, each showing the Preyer reflex. The average weight of the animals was 550 g. The animals were divided into three groups: a group of five animals for drill noise level measurements, a group (20 animals) to be studied and a control group (20 animals). For the experiment the animals were anaesthetized with a 10% solution of urethane injected intraperitoneally. Except for the first group (5 animals), the approach to the cochlea was obtained through a special surgical procedure ensuring minimum injuries to the inner ear. Only one ear of each guinea pig was tested.

In the experiment a surgical drill (DF Treffurt) with the maximum speed of 16 000 rpm and a standard diamond bit were used. Prior to the proper experiment, the drill's noise level was measured by an acoustic level meter while drilling the bulla of an anaesthetized guinea pig belonging to the first group. The meter's microphone was set about 5 cm from the place of drilling. The average acoustic spectrum of the drill's noise is shown in Fig. 1.
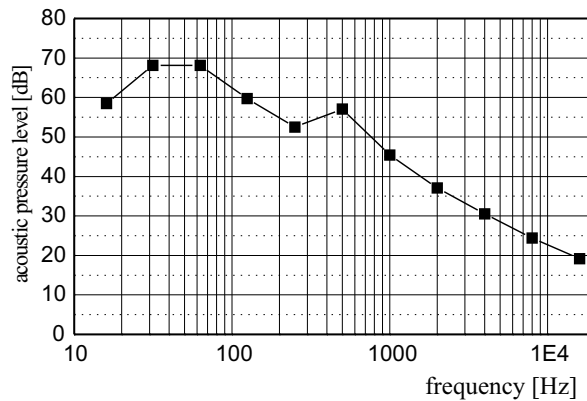

Fig. 1. Drilling noise level versus frequency for the surgical drill used in the experiment.

The drill noise level was below 60 dB in the frequency range (260 Hz–8 kHz) used in the experiment.

A block diagram of the experimental setup is shown in Fig. 2 [7]. A sinusoidal generator with two synchronous outputs was used. The sinusoidal signal of a specified frequency and amplitude (output 1) was amplified and delivered to a headphone. The signal produced a sinusoidal acoustic wave of a fixed frequency and pressure level in the

guinea pig's external auditory canal. The synchronous signal of the generator's second output was connected to the reference input of a lock-in amplifier. The cochlear microphonics (CM) were picked up from the surface of the cochlea by a platinum electrode and synchronously detected in the lock-in amplifier. The CM signal values were used as a measure of the cochlea's electric activity.
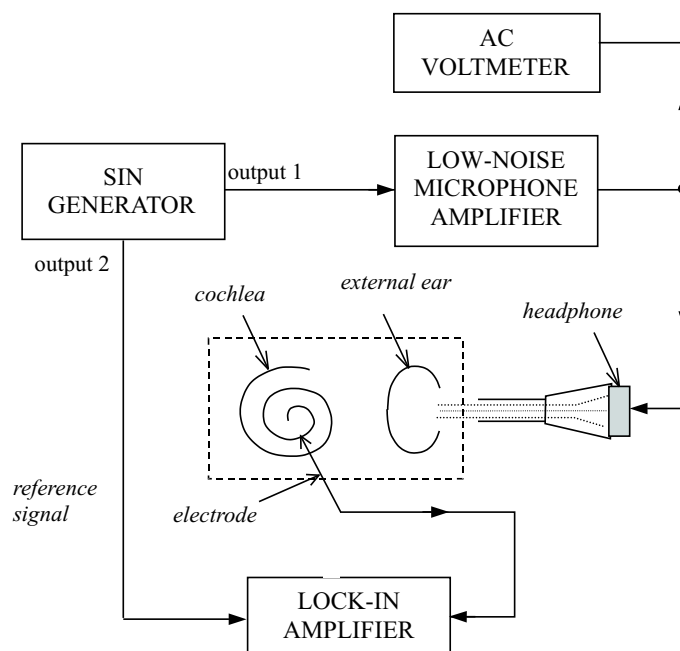

Fig. 2. Experimental setup.

Six measurement frequencies: 0.25, 0.5, 1.0, 2.0, 4.0 and 8 kHz were used in the experiment. For each of the frequencies, nine different intensity levels of the acoustic wave (55–95 dB with a step of 5 dB) were adopted. Consequently, each complete test of the state of the cochlea yielded 54 CM values. The CM signals were picked up in identical external conditions (ambient temperature and air humidity) and from the same places on the surface of the cochlea: for frequencies below 4 kHz – from the cochlea's apex and for 4 kHz and 8 kHz – from its base. The measured CM signal values were in a range of a few microvolts for the 55 dB sound pressure level and up to a few hundred microvolts for the 95 dB level. The lowest CM signal values were always registered at a measurement frequency of 4 kHz.

The electric activity of each guinea pig's cochlea in the studied group was tested three times: immediately after opening the bulla, after 30 minutes of surgical drilling activity on the bone surrounding the guinea pig's cochlea and 150 minutes after opening the bulla. The first test was performed to fix the reference levels for CM values at the particular measurement frequencies and acoustic pressure levels. The second test was

performed to evaluate the post-drilling shock. The third test was performed to assess the long-term injuries to the cochlea. Preliminary tests conducted for a few hours had shown that the shock-drilling effects last for about one hour and so the long-term injuries were measured two hours after the drilling ended. Hence three CM values: $(CM)_0$, $(CM)_{0.5h}$ and $(CM)_{2.5h}$ were obtained for each of the measurement frequencies and sound pressure levels, respectively.

In the control group, the cochlear electric activity was tested only twice: immediately after opening the bulla and 150 minutes later. Thus only two CM values: $(CM)_0^{ctrl}$ and $(CM)_{2.5h}^{ctrl}$ were obtained for each guinea pig, respectively.

In the experiment, aspiration was applied for a few seconds immediately prior to the cochlea function test in order to prepare the cochlea's bony shell for contact with the measuring electrode.

3. Post-drilling shock

The post-drilling shock of the cochlea's electric function could be studied by comparing the results of the test performed immediately after drilling with those obtained before drilling. For each of the animals, the comparison was made at the same measurement frequencies and acoustic pressure levels. For this purpose the coefficient

$$\kappa_1 = \frac{(CM)_{0.5h}}{(CM)_0} \tag{1}$$

was defined and its mean values $(\kappa_1)_{mean}$ were calculated for the whole group studied. The results for each of the measurement frequencies are shown as $(\kappa_1)_{mean}$ versus sound pressure level in Fig. 3.
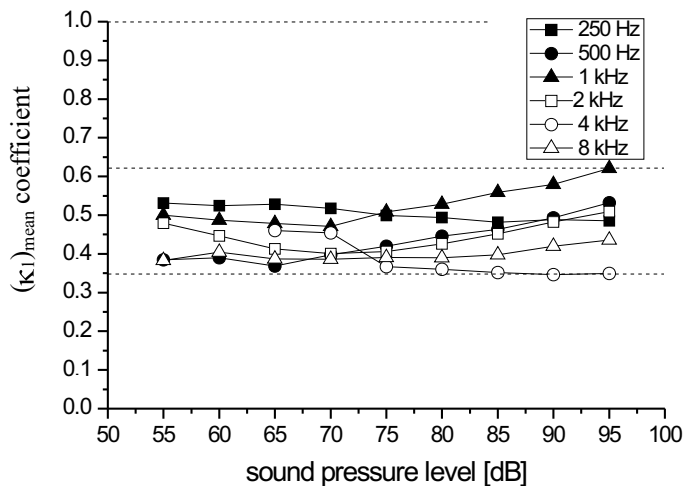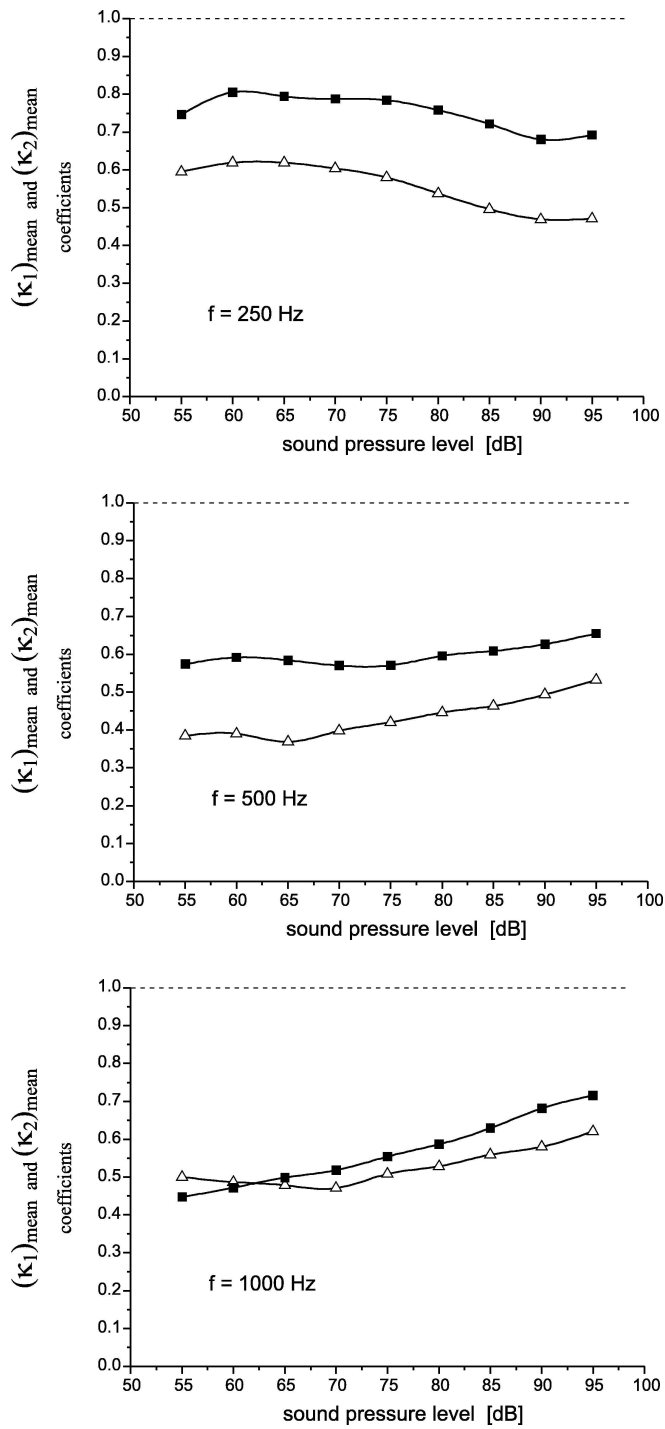

Fig. 3. Dependence of the $(\kappa_1)_{mean}$ coefficient on the sound pressure level for six measurements frequencies.
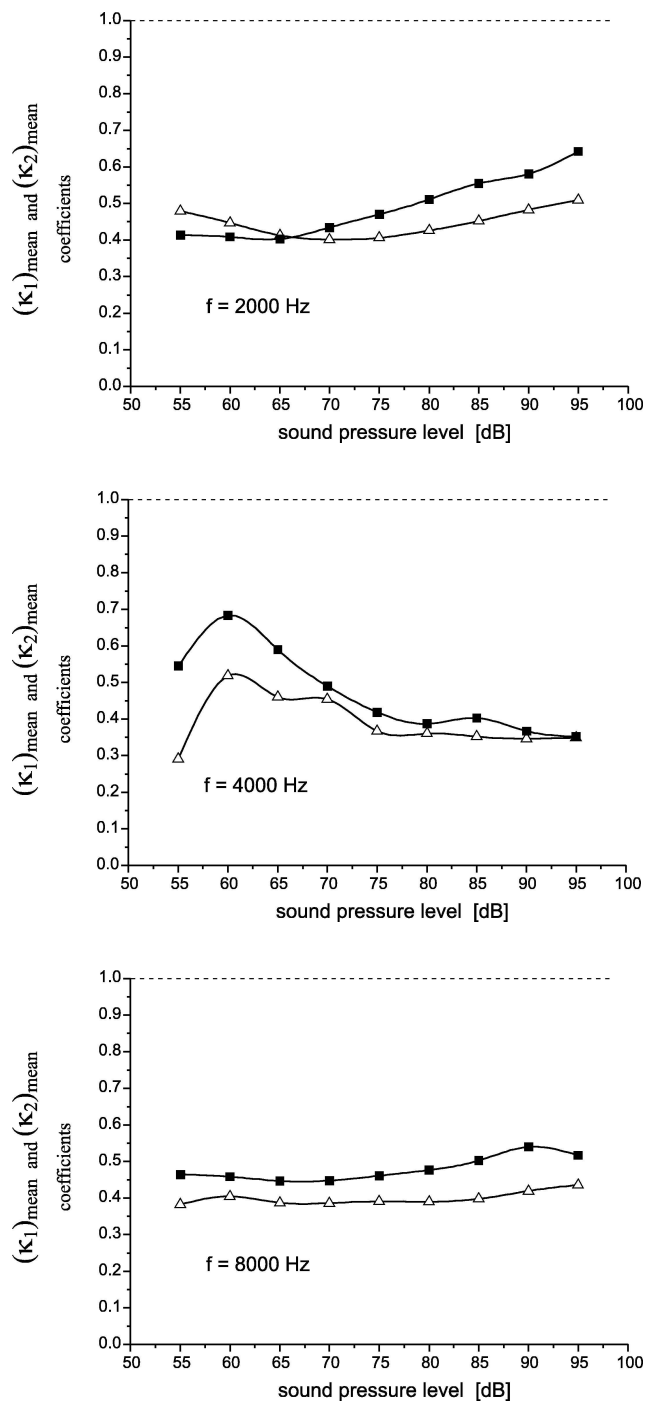
[FIG. 4]

Fig. 4. Comparison of the mean values of the κ_1 and κ_2 coefficients versus sound pressure level for six measurement frequencies. Marks: △ – immediately after drilling, ■ – two hours after end of drilling.

All the calculated 54 values of $(\kappa_1)_{\mathrm{mean}}$ are below 1.0 and they are within the range of 0.35–0.65. This means injury to the cochlea electric function at all the 54 measuring points.

From the practical point of view, it would be interesting to find out if self-recovery of hair cells (which are the source of CM signals) is possible. To ascertain this, for each of the animals at each of the measurement frequencies and acoustic pressure levels, the coefficient

$$\kappa_2 = \frac{(\mathrm{CM})_{2.5\mathrm{h}}}{(\mathrm{CM})_0} \tag{2}$$

and its mean values $(\kappa_2)_{\mathrm{mean}}$ were calculated. The recovery processes could be studied by comparing the mean values of the two coefficients: (1) and (2).

The results of the comparisons are shown in Fig. 4. It is apparent that at each of the measurement frequencies an increase in the CM values depends on the sound pressure level.

4. Long-term consequences of drilling

In order to assess accurately the effect of drilling on the cochlea's electric function, the results obtained for the guinea pigs belonging to the studied group were compared with the results obtained for the control group guinea pigs. To this end, the latter results were handled statistically in the same way as in the case of the studied group. At first, for each of the guinea pig control group and for each of the measurement frequencies and acoustic pressures, the coefficient

$$\eta = \frac{(\mathrm{CM})_{2.5\mathrm{h}}^{\mathrm{crtl}}}{(\mathrm{CM})_0^{\mathrm{crtl}}} \tag{3}$$

was defined and then its mean value η_{mean} was calculated. The results obtained for both the groups were compared for 54 measuring points. The $(\kappa_2)_{\mathrm{mean}}$ and η_{mean} coefficients versus acoustic pressure level (in [dB]) for the six measurement frequencies are shown in Fig. 5.

It should be noted that after 2 hours the CM values in the studied group are always below the initial ones ($\kappa_2 < 1$). Besides, $(\kappa_2)_{\mathrm{mean}}$ coefficient is always lower than the η_{mean} coefficient. Both these facts testify the permanent damage of the cochlea's electric function caused by drilling.

5. Discussion

In the light of current knowledge, a full explanation of the obtained results is very difficult and even impossible. A qualitative explanation can be based on the hearing theory and the anatomy of the cochlea. An external acoustic stimulus causes motion of the basilar membrane (BM). The inner hair cells (IHC) convert the mechanical energy
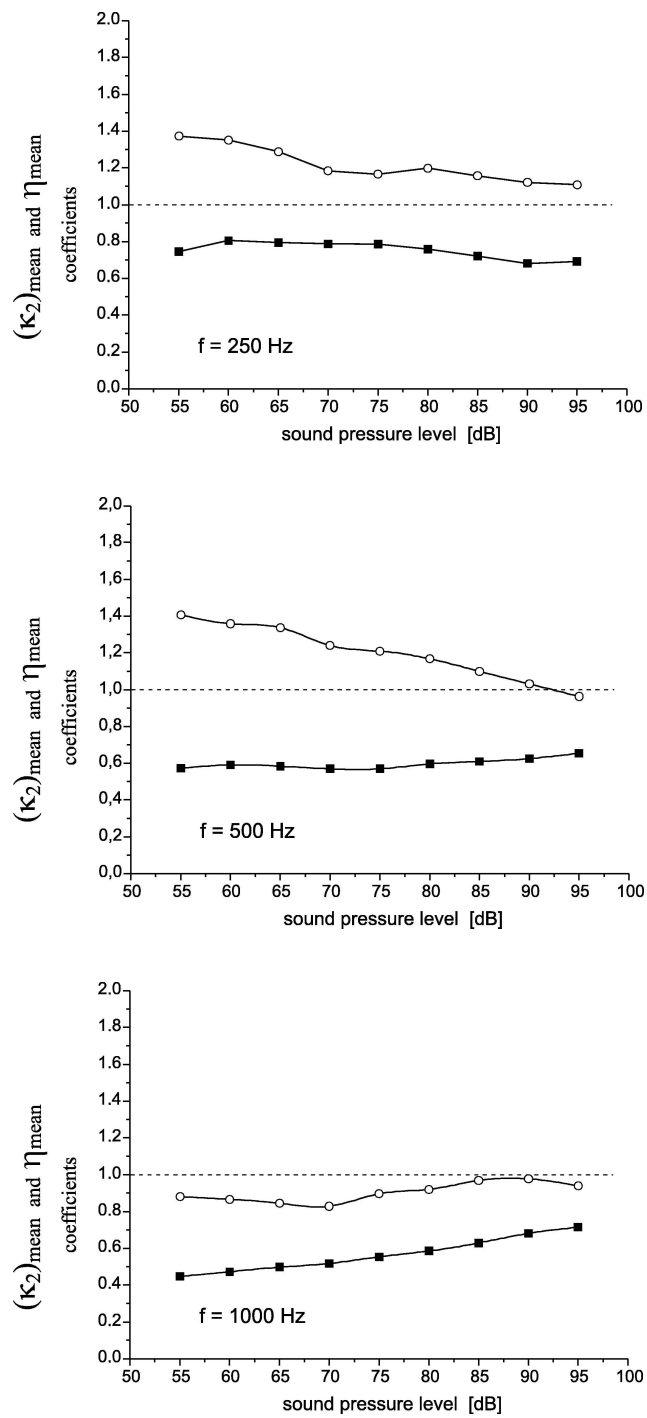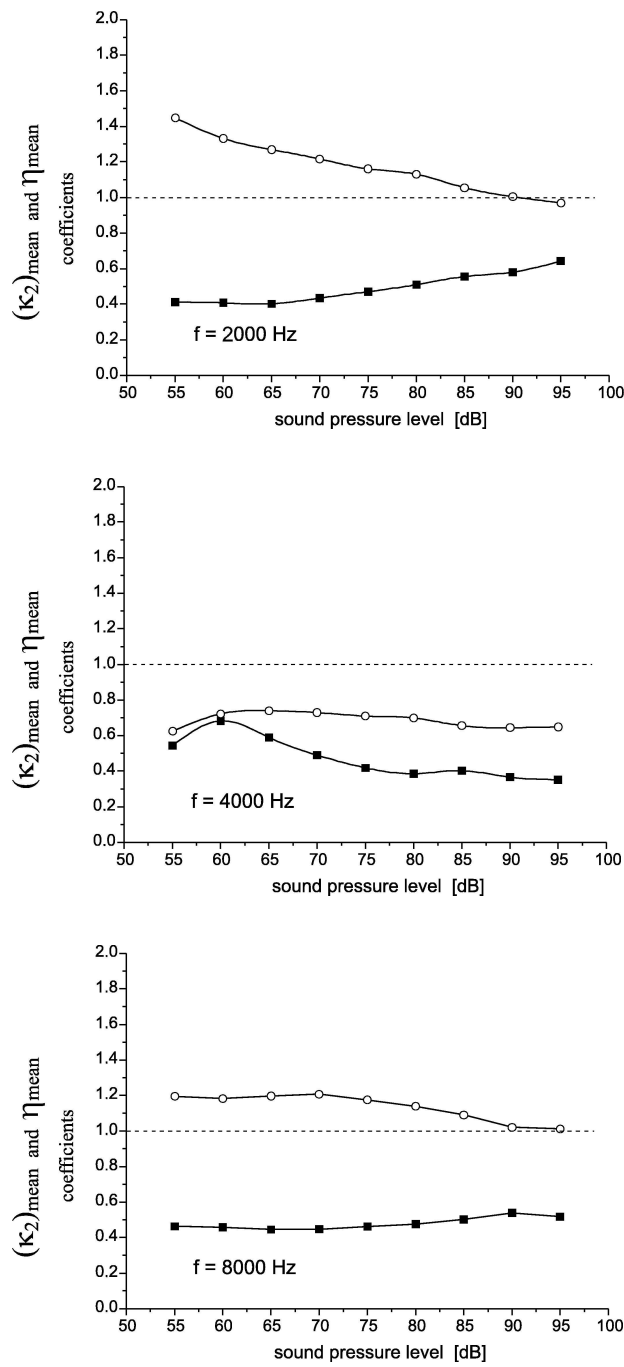
[FIG. 5]

Fig. 5. Comparison of coefficients $(\kappa_2)_{\mathrm{mean}}$ (studied group) and η_{mean} (control group). Marks: ■ – studied group, □ – control group.

of the motion into electric energy which excites the afferent nerve fibres. The outer hair cells (OHC) determine the overall sensitivity and frequency selectivity of the auditory system [1–3]. When the OHCs are damaged, the auditory system can function, but the threshold is by about 50 dB higher and the BM's frequency-selectivity decreases. When the level of the acoustic stimulus is below 60–80 dB, the OHCs play a fundamental role in the hearing process (their function is referred to as the cochlear amplifier in the literature). Above 70 dB, the role of the cochlear amplifier is marginal and the IHCs determine the perception of the acoustic stimulus. According to the current theory of hearing, different groups of hair cells (both OHC and IHC) react to different frequencies of the acoustic stimulus. Hair cells sensitive to the lowest acoustic frequencies are located at the apex of the cochlea while those sensitive to the highest frequencies are situated at its base.

The BM and hair cells of both types can be injured during drilling. On the basis of the studies made, it is very difficult to determine which of the elements are most severely injured. Probably the three elements mentioned above are injured simultaneously, but the degree of injury depends on the measurement frequency and the sound pressure level.

The six curves shown in Fig. 3 illustrate the shock-drilling effect. Each of the curves represents nine measurement points. The time needed to measure each single curve was 3–5 minutes. The first measurement frequency immediately after the end of drilling was 250 Hz. The measurement of each next curve was shifted in time. The last curve was measured (at 8 kHz) about 20–25 minutes after the end of drilling. Recovery began immediately after the end of drilling, i.e. all the curves were measured during the recovery process. For this reason, the curve obtained for the frequency of 250 Hz best illustrates the shock effect. A comparison of the six curves shows that the recovery of the electric cochlea function starts with IHCs.

The final result of the recovery processes is shown in Fig. 4. Two hours after the end of drilling an increase in the CM values is observed (except for the CM values measured for the 1 kHz and 2 kHz frequencies at 55–65 dB sound pressure levels) . The size of the increase is better visible in Fig. 6 where $\Delta(\kappa) = (\kappa_2)_{\mathrm{mean}} - (\kappa_1)_{\mathrm{mean}}/(\kappa_1)_{\mathrm{mean}}$ versus sound pressure level is presented for the six measurement frequencies.

The increase in the CM values depends on the parameters of the acoustic stimulus used and ranges from -10% to $+60\%$. With the exception of the 500 Hz acoustic stimulus, a larger increase in CM values is observed at higher sound pressure levels, which may indicate that OHCs are injured more than IHCs during drilling. The situation at the 500 Hz acoustic excitation is exactly opposite. The difference may be due to a more severe injury of the basal membrane at the apex of the cochlea where the amplitude of vibration during drilling is the largest.

Recovery at all the measured CM values is only partial as the comparison of coefficients $(\kappa_2)_{\mathrm{mean}}$ and η_{mean} in Fig. 5 shows. The curves of $(\kappa_2)_{\mathrm{mean}}$ and η_{mean} vs. sound pressure at the particular measurement frequencies do not coincide. The $(\kappa_2)_{\mathrm{mean}}$ vs. sound pressure level curves are always below the corresponding η_{mean} curves. In order to better illustrate the fact that the recovery of the cochlea's electric function is only partial, the $(\kappa_2)_{\mathrm{mean}}/\eta_{\mathrm{mean}}$ dependence (in per cent) is presented in Fig. 7.
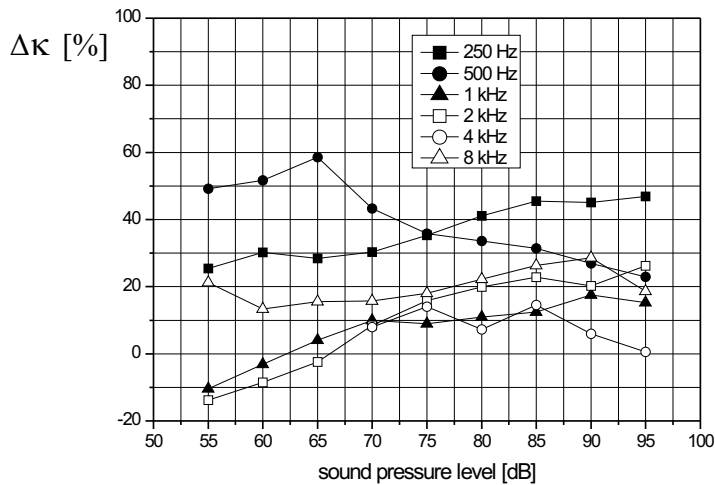
Fig. 6. Percentage changes in the CM values two hours after the end of drilling.
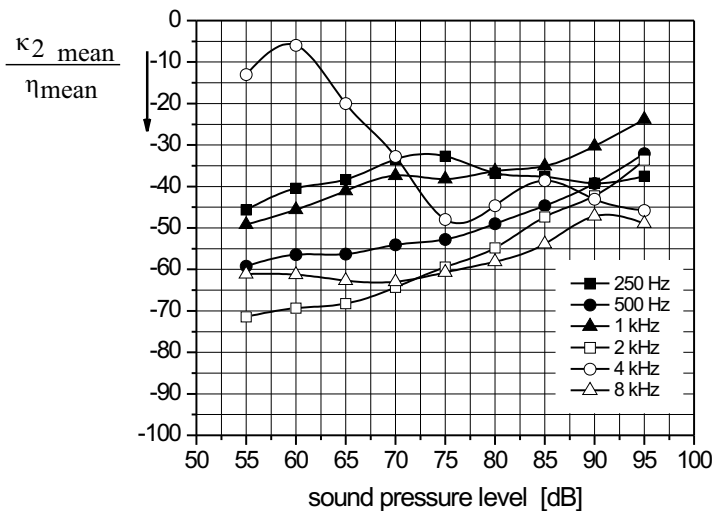

Fig. 7. Percentage decrease in the CM values in the studied group in comparison with the control group.

The largest fall in the CM values amounts to 70% (at a 2 kHz stimulus and a sound pressure level of 55 dB) and the smallest one to 6% (at a 4 kHz stimulus and a sound pressure level of 60 dB). The size of the fall depends on two parameters of the acoustic stimulus: its frequency and sound pressure level (in the case of the human ear, a change in the timbre of received sounds occurs). Except for the frequency of 4 kHz, the IHCs suffer a little less injury caused by drilling than OHCs do. At the 4 kHz stimulus and within a sound level range of 55–65 dB, the injury to OHCs is very small. The frequency

of 4 kHz is unique: in the experiment presented here and in all the earlier experiments, the CM values were always much lower than those measured at other frequencies for the same sound pressure level. No explanation of this fact can be found in the literature.

To sum up, a thirty minute drilling caused permanent damage to the cochlea. The damage can be ascribed to the injury to the IHCs, OHCs and the basilar membrane.

6. Conclusions

On the basis of the experimental results obtained the following conclusions can be drawn:

1. A 30-minute non-stop drilling of the skull bones surrounding the guinea pig's cochlea causes a damage to the electrophysiology of the cochlea.
2. In the studied group, the CM values never returned to the initial ones.
3. Drilling can change the characteristics of hearing by altering the electric response of the cochlea to particular acoustic wave frequencies and intensities.
4. The experiment confirms that the cochlea may suffer damage during a prolonged inner ear operation.
5. The noise spectrum of the drill used in the experiment was below 60 dB, which means that vibrations of the bone during drilling were the primary cause of damage to the cochlea's electric function.

The experiment shows that the use of a drill in ear surgery can be a real hazard to the cochlea's electric function and it may impair the beneficial effects of the surgery.

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