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Shockwave-induced Compound Action Potentials in the Peripheral Nerve

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Summary. To verify a presumed interaction between shockwaves arisen by impacts of high velocity projectiles and nervous tissue an electrophysiological experiment is performed with the following results: In peripheral nerves regular compound action potentials (CAPs) are provoked by shockwaves the amplitudes of which are increased corresponding to the pressure intensity of the shockwaves. The nerve shows no electrical activity below a certain pressure threshold (0.75 bar). Saturation of the CAP amplitude occurs beyond a pressure limit of 8 bar.

Key words: Shockwave, interaction with nervous tissue – Impacts of projectiles, shockwaves

Zusammenfassung. Mit Hilfe eines ausführlich dargestellten Versuchsaufbaues wird gezeigt, daß durch Geschoßeinwirkung entstehende sogenannte Schockwellen an peripheren Nerven Summenaktionspotentiale (CAP) ausgelöst werden können. Die Amplitude des CAP steigt zunächst mit zunehmendem Schockwellendruck an, erreicht aber dann eine Sättigung bei ca. 8 bar. Der Nerv zeigt keine elektrische Aktivität unterhalb einer Schockwellenamplitude von 0,75 bar.

Schlüsselwörter: Schockwellen, Auswirkung am peripheren Nerven durch Geschoßeinwirkung – Geschoßeinwirkung, Schockwellen

Introduction

Impacts of high velocity projectiles not only cause tissue destruction but also induce shockwaves spreading throughout the body [1]. A connection may be possible between these shockwaves and cases of sudden death observed after a body was hit by high-velocity projectiles which were not evidentially traceable to the extent of surgical injury [2]. One should discuss a danger to body (especially to

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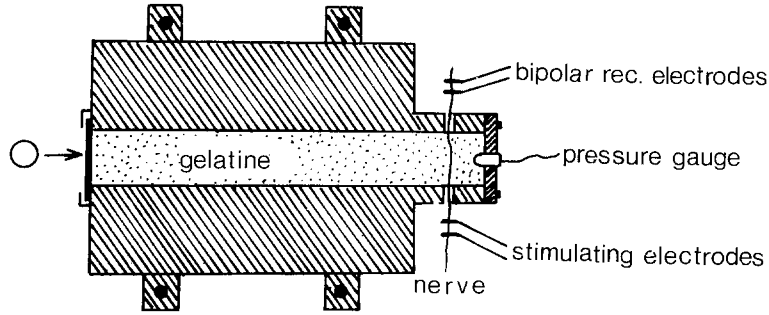

Fig. 1. Mechanical part of the experimental arrangement

the heart) arising from interactions between impact-induced shockwaves and nervous tissue because it is known that

1. thrusts evoke electrical activity in excitable tissue even if it is not adequate for mechanical reception (e.g., optical sensation of a flash after a hit on the back-head [3]; excitation of the heart by thrusts of thin plastic rods [4]) and

2. transthoracic cardiac stimulation is possible by use of pressure waves [5].

Considering that in addition to the heart there are some more nervous structures in the mediastinum precisely coordinating the heart beat, each of which being able to disturb the electrical process of the heart beat by irregular excitation, we intended to look for the electrical behaviour of a nerve after systematic shockwave application. We expected that it should be possible to raise regular action potentials in a peripheral nerve by the effect of sudden pressure gradients. This would mean that not only electrical but also mechanical energy would provoke nervous excitation.

This assumption was to be verified in the following experiment.

Methods

The following experimental arrangement is a modification of an experiment well known in the classical electrophysiology (Fig. 1) [6]:

In an iron bar fixed on a table a cylindrical hole of about 4 cm in diametre is drilled. This space is filled with Ringer's gelatine. At one end of the hole a sciatic nerve of an oxfrog is put into a little channel perpendicular to the axis of the hole. Outside the channel the nerve is laid on two stimulation electrodes on one side and on two bipolar recording electrodes on the other. The stimulation electrodes are connected with a square wave generator, the bipolar recording electrodes are connected with the imput of an oscilloscope. At this end the opening of the hole is closed with a plate containing a pressure gauge converting the time-dependent pressure amplitude into an electrical signal recorded by an oscilloscope. The other end of the hole is closed by a thin steel membrane to apply impacts by little steel balls. The experiment is performed in two steps:

1. To prove that the nerve is intact it is stimulated by an electrical square pulse of some volts and a duration of about 1 ms. The compound action potential (CAP) excited in this manner is measured by the bipolar recording electrodes and stored by an oscilloscope.

2. Shockwaves of variable amplitudes are generated by impacts of little steel balls on the metallic membrane described as above. Near the nerve time-dependent pressure variations are arisen; one of them is shown in Fig. 2.

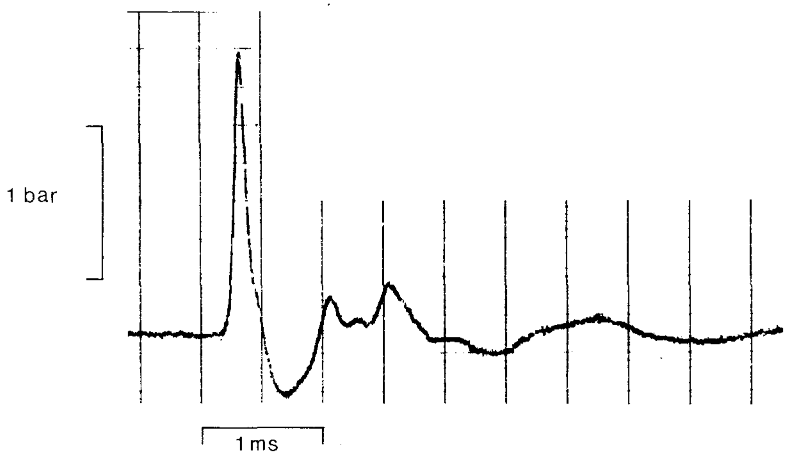

Fig. 2. The time-dependent pressure curve in gelatine in the near of the nerve

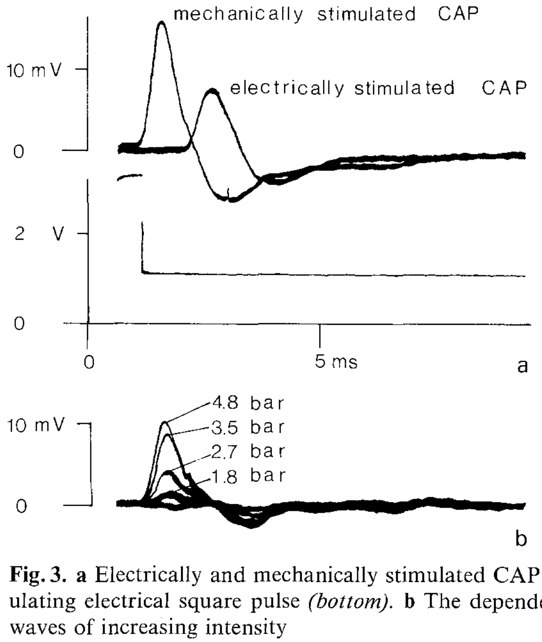

Fig. 3. a Electrically and mechanically stimulated CAP in the peripheral nerve *(top)* and stimulating electrical square pulse *(bottom)*. **b** The dependence of the CAP amplitudes on shockwaves of increasing intensity

Results

Figure 3 shows the results of the experiment: A voltage pulse of about 3 V dc and of a duration of about 1 ms is given to the stimulation electrodes (see the lower trace of Fig. 3a). This voltage pulse triggers the typical CAP (see the upper trace of Fig. 3a) beginning 2 ms after the start of the stimulus. The time delay between the start of the stimulus and the beginning of the CAP is caused by the propagation time between the two pairs of the electrodes. Now, applying the shockwave in the manner described above the nerve is excited in a similar way. The voltage curve received is equal to the shape of a CAP, however, exceeding the electrically generated one in the amplitude and starting earlier. The earlier appearance of the mechanically induced CAP is explained by the experimental process: In any case the oscilloscope is triggered by electrical and mechanical stimulus, respectively. However, the distance from the bipolar recording electrodes to the position where the mechanical stimulus is applied, is shorter than the distance to the position of the stimulating electrodes. Therefore, the time interval between the stimulation and the observation of the CAP must be different in both cases.

The intensity of the CAP is expected to be dependent on the amplitudes of the shockwaves. This dependence is shown by the observation (Fig. 3b), that the intensity of the CAP is increased corresponding to the increase of the shockwave amplitudes applied (1.8 bar; 2.7 bar; 3.5 bar; 4.8 bar). Below a threshold of 0.75 bar no CAP is raised. Saturation of the CAP amplitude occurs beyond 8 bar of pressure.

Conclusions

From the experimental results the following conclusions can be drawn:

1. Shockwaves produce mechanical irritations generating electrical activity (CAPs) in the peripheral nerve.
2. The shockwave intensity must exceed a certain pressure threshold of about 0.75 bar to provoke a CAP.
3. The dependence of the CAP amplitude described as above is caused by the fact that the number of the fibres excited in the peripheral nerve is depending on the applied pressure amplitude.
4. The mechanical irritation of nervous tissue shown in our simple experiment could be of certain importance for wound ballistics because measurements have shown that there occur pressure amplitudes in the mediastinum after a hit on the thorax in the region of the ventral projection of the heart which are in the range of some bars [7]. Considering that there are some important nervous structures in the mediastinum (vagus, sympathetic nerve, the heart itself) a disturbance of the electrical process of the heart beat seems to be possible similar to the cardiac disturbances due to single electrical shocks applied during the vulnerable phase of the systole [8].

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