1.1 Effects and Side Effects of Shock Wave Therapy

In this chapter, currently known effects and side effects are presented. We first present a lecture held by Dr. Pia Steinbach at the First Shock Wave Symposium in Kassel in April 1996. It especially features the results she achieved with regard to a dose-effect relationship at the endothelium of the blood vessels, as well as the influence of shock waves on the membrane potential of the neuron.

1.1.1 Summary of the Lecture of Dr. Steinbach

As is widely known, shock wave therapy has been employed longest for the crushing of kidney stones. However, in the meantime it is also employed to crush other calculi, such as gallstones, pancreatic and salivary calculi.

High energies are required to crush such stones. The mode of action concerning the destruction of stones is believed to be known. Interaction occurs at the interface of the liquid medium and the kidney stone, because the acoustic resistance or difference in impedance between the two materials is very high. This interaction leads to changes at the surface of the renal calculus. Pressure and shear loads occur at the transition from the liquid to the stone due to a jump in the acoustic impedance (water $1.49 \times 10^5$ g/cm$^2$; kidney stone $5.6-14.4 \times 10^5$ g/cm$^2$; Sucul et al. 1993). Water infiltrates the cracks which have been created on the surface of the stone. A further effect comes to bear, namely cavitation, i.e. gas bubbles develop in the water due to the rapid interaction between pressure and shear. The collapse of the gas bubbles also leads to the development of very fast flows, the so-called jet streams, whose impact on the stone surface leads to its further disintegration.

There are other indications for employing high-energy pressures: tumour therapy, albeit as yet only in an experimental framework. It is presumed that the destructive effect on the tumour bears on both the vascular system of the tumour and directly on the tumour cells. The effect can be enhanced by also administering cytostatic drugs. The side effects on soft tissue occurring in lithotripsy of renal calculi are employed in tumour therapy. However, the mode of action is not as clear in tumour therapy. In the literature, the preferred explanation is cavitation, whereby the development of radicals is especially believed to play an important role. The mechanical effects of cavitation, such as the jet streams, can however also contribute to the destruction, especially of the vascular system. The influence of the direct impact of the
pressure wave, which plays a decisive role in the destruction of stones, may be less important, as the differences in impedance in tissue are small.

In the following, I should like to consider two indications more thoroughly, in which the modes of action are as yet unknown: namely, the effect of shock wave therapy in the healing of bone fractures, where high pressures are also employed, and secondly, the effect in palliative therapy.

Beforehand, however, I should like to elucidate the difference between the shock waves used in lithotripsy and the waves employed in diagnostic ultrasound. Shock waves are characterized by high positive pressures up to 80 MPa and negative pressures of 5–10 MPa. Furthermore, they have a short rise time of 30–120 ns and a shorter pulse duration (5 μs). In contrast to ultrasound, shock waves have low frequencies. Just in this respect, there is less absorption by the tissue. Moreover, the shock waves are applied with a lower repetition frequency of 1–2 Hz, maximum 4 Hz, which means that they have a low time-averaged intensity. The only thing that can be said for sure is that the shock wave does not cause tissue warming. None of the known shock wave effects are due to thermal effects.

**Effects of Shock Waves on Bones**

There is as yet not much literature that deals with this topic. I should like to refer to two works, one of which is by Sukul and Johannes (1993). They treated formalin-fixed rabbit bones, i.e. femur and tibia, in vitro with the Lithostar Plus. The macroscopic defects found were a decortication, occurrence of bone fragments, a complete cortical bone defect and the occurrence of fractures. These effects occurred after application of 1000–2000 pulses of 0.6 mJ/mm² (which corresponds to the upper limit in the treatment of renal calculi). No further defects were found after 5000 pulses. The lower the energy density was, the later effects occurred. The severity of damage correlated with the energy density; however, no correlation was found with the number of pulses applied.

As a reservation, it should be noted that the tests were carried out on formalin-fixed bones. It remains unclear as to whether the acoustic properties of the bones were altered due to the fixation process. The mode of action presumed and discussed is the same as in the treatment of kidney stones, i.e. that microfissures develop and cavitation bubbles occur. This is per se logical, as the acoustic impedance of a kidney stone roughly corresponds to that of bone.

The second study I should like to refer to is that by Delius and coworkers (1995), in which they studied the effects on the rabbit femur in vivo using the experimental device (XL 1) by Dornier.

Here, 1500 pulses with a voltage of 27.5 kV at a frequency of 1 Hz were applied. Ulcerations of the skin at the point of entry of the shock wave, soft-tissue swelling in the lower third of the femur, microscopic changes of the bone (detachment of the periostium, subperiosteal haemorrhages and escape of bone marrow) were encountered. Furthermore, diffuse haemorrhages at a distance of 10 mm from the focus and haematomae close to the focus in the medullary space in association with fractured trabeculae were found. At fol-