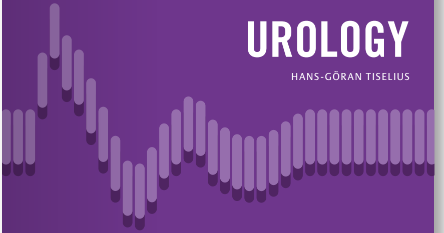
SHOCK WAVE
THERAPY
IN PRACTICE



UROLOGY

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SHOCK WAVE TECHNOLOGY FOR STONE FRAGMENTATION

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Shock waves in medicine have proven effective in non-invasive kidney stone fragmentation since 1980. To date there are 3 different shock wave generation methods in clinical use, electro-hydraulic or spark-gap, piezoelectric and electro-magnetic technology, by either flat coil with an acoustic lens or by cylindrical coil with a parabolic reflector.

Important shock wave parameters are peak pressure and pressure time profile, focal dimensions and energy values as well as energy flux density measured within and outside of the focal zone of the shock wave field.

Fragmentation of stones takes place due to direct impact of shock wave energy and subsequent cavitational effects generated by shock waves.

Application of shock waves may be selected with respect to energy level, number of shock wave pulses and repetition frequency. Different treatment regimes may have an impact on soft tissue which has to be passed by the shock wave before the target stone is hit. Balancing all treatment parameters is essential to optimize fragmentation results and to minimize small but potential side effects.

INTRODUCTION

Shock wave application in medicine dates back to the late 1950's, when L.A. Yutkin, a Ukrainian engineer, developed URAT 1, a device for intracorporeal shock wave fragmentation of human bladder stones through an endoscope. As early as 1913, Wappler had already performed technical experiments with shock wave fragmentation by sparks brought in contact with bladder stones. He used a thin, isolated wire through a urethroscope [1].

A breakthrough took place in 1980, when Chaussy et al. [2,3] fragmented the first human kidney stone with shock waves applied extracorporeally in vivo in Munich Grosshadern. The innovative approach was to generate shock waves

From a medical point of view, shock waves have the beneficial attribute of passing through living tissue without causing major lesions and – simultaneously – exceeding the cohesiveness values of brittle material, e.g. kidney stones. They can be generated by technical means outside the human body, sent through soft tissue to the target stone and can selectively break stones into small sand-like pieces. Shock waves are generated as short pressure pulses with a time duration in the range of one microsecond and a repetition frequency of a few pulses per second.

Due to the short time duration, shock waves can be focussed on small focal areas of several millimetres by means of acoustic reflectors or lenses. Utilizing focal zones with dimensions comparable to human kidney stones and fractions of those helps to concentrate the shock wave energy on the stones themselves and keep it low anywhere else in the tissue. This additional feature simultaneously reduces possible side effects and enhances fragmentation efficiency.

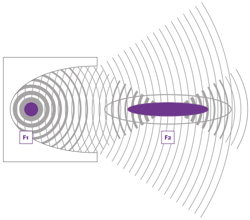
SHOCK WAVE GENERATION METHODS

ELECTRO-HYDRAULIC SHOCK WAVE GENERATION

Historically, the first method of medical shock wave generation was based on the so-called electro-hydraulic principle. Two electrodes at a distance of approx. 1 mm are exposed to a high electrical tension of approx. 20 kilovolts in a water bath. A high-intensity spark is generated by the electrical breakdown of the isolating medium (water) in-between. A plasma channel is heated up and rapidly expands with an expansion velocity slightly higher than the speed of sound in water (≥ 1500 m/s). The surrounding water is compressed, and the pressure distortion is radiated as an almost spherical shock wave into the medium, centred on the origin of the spark. A spherically expanding wave dissipates shock wave energy with decreasing pressure amplitudes unless the diverging wave is turned into a converging wave by some kind of focussing. Electro-hydraulically generated shock waves are usually focussed by a hollow ellipsoidal reflector with the spark gap positioned in the first focal spot. The shock waves are reflected on the inner surface of the ellipsoid and converted into a converging spherical wave centred on the second focal spot.

An underwater spark generates spherical shock waves

SPHERICAL SHOCK WAVES GENERATED BY AN UNDERWATER SPARK IN THE FIRST FOCAL SPOT F1 OF A SEMI-ELLIPSOID | *Fig. 2*



The main part is concentrated within an area around F2, the second focal spot of the ellipsoidal structure.
A smaller part of the primary spherical wave does not hit the reflector wall and is radiated as a vagabonding wave without being focussed

The hollow ellipsoidal structure is not necessarily an entire or closed ellipsoid but may be truncated near an equatorial line so that the second focal spot is distant from the solid reflector structure. This makes it possible to position a patient in front of the reflector in order to place a target stone in the second focal spot. This is the area of the highest shock wave energy outside of the origin of the spark and is well suited to break kidney stones. Everywhere else, the energy density is lower and possible side effects are reduced.

An ellipsoidal reflector focuses main part of the spherical shock wave and radiates a smaller part as vagabonding wave unfocussed into the tissue

COLLAPSE OF A CAVITATION BUBBLE (SCHEMATIC) CLOSE TO AN ACOUSTIC INTERFACE (STONE SURFACE) | *Fig. 13*

Due to asymmetric streaming conditions at the interface, an asymmetrical collapse occurs and generates a microjet directed towards the interface. Microjets featuring velocities up to several hundred m/s affect the interface and contribute to erosion and stone fragmentation as well as tissue lesions

DESIRABLE AND UNDESIRABLE SHOCK WAVE EFFECTS

According to Paracelsus (1493-1541) there is no beneficial medical effect without an unwanted side effect. This general statement also holds true for shock wave application even if side effects are rare and usually mild [10,11,12]. Nevertheless, desirable effects have to be balanced against undesirable side effects.

Fragmentation power and possible tissue lesions have to be balanced

Microjets caused by collapsing cavitation bubbles close to vessel walls may also punch micro holes into small vessels, which in turn are responsible for micro bleedings. Under rare unfavourable conditions (bleeding disorders e.g.), haematomas may occur that occasionally require medical intervention.

Obviously, shock waves also affect the nervous system by generating sensory inputs, usually perceived as spiky pain. Depending on the applied energy level, pain killers or even anaesthesia measures may be appropriate. If shock waves interfere with the cardiac excitation system, extra systoles may be triggered and cause cardiac arrhythmia. In these rare cases, the release of shock waves should be triggered by the patient's ECG.
Bony structures exposed to shock waves may cause distortions of straight propagation and absorb shock wave energy, reducing fragmentation efficiency.

HOW TO APPLY SHOCK WAVES

FOCUSSING

All the mentioned side effects demand a precise control of shock wave exposure with respect to optimal energy level selection, energy passage avoiding bony obstacles and excessive shock wave dosing to tissue areas outside the pre-selected target area.

From a technical point of view, focussing is the appropriate measure to concentrate shock wave energy exactly on the point of interest and keep it as low as possible anywhere else. Since extracorporeal shock wave applications require a transmission pathway from the body surface to the stone, the energy density should be kept low by coupling shock waves over a large skin area and by precise concentration at the treatment area around the focus. Corresponding large aperture systems with large aperture angles and small focal areas simultaneously confine the effective area and possible tissue lesions to a small region, avoiding tissue lesions in front or behind the focal zone.

A well focused shock wave provides high fragmentation efficiency while, simultaneously, side effect

Precise focussing works best with frequent position control of the target area using localization devices such as fluoroscopy or sonography and enables maximum fragmentation efficiency as well as the simultaneous spatial confinement of possible tissue lesions.

In the case of significant respiration-related target dislocation, however, a slightly increased focal extension may keep the stone on target more easily.

According to the different demands in clinical shock wave application, a selectable focal size can help to adjust to different cases in routine treatments.

SHOCK WAVE DELIVERY RATE

Due to the persistence of cavitation bubbles generated by shock waves, application rates exceeding 1 Hz may reduce the fragmentation efficiency by blocking energy exposure to the stone. It is therefore advised to use shock wave delivery rates of 1 Hz or even lower [13].

Slow shock wave repetition rates (≤ 1Hz) increases efficiency and reduces side effects