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An Insight of Shock Wave Lithotripsy (SWL)

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Abstract

Background: A collaboration of technicians, urologists of the hospital of the Ludwig Maximilians-University in Munich, Germany, and industrial companies led to the development of the first standard lithotripter “Human Model 3” (HM3) in 1980. The revolutionary finding was that shock waves may pass through living tissue without significant injury or side effects while being simultaneously strong enough to fragmentize hard urinary stones. The key reasons are the following: first, elasticity of living tissue, which may pass high transient pressures up to 100 MPa (1,000 bars) and more; second, the possibility to couple acoustic energy with low intensity into the body and concentrate (focus) it on the region of interest, the stone to be fragmented.

Keywords: Shock Wave Lithotripsy (SWL)

Introduction

A collaboration of technicians, urologists of the hospital of the Ludwig Maximilians-University in Munich, Germany, and industrial companies led to the development of the first standard lithotripter “Human Model 3” (HM3) in 1980 **(1)**
On February 7, 1980, in Munich, Germany, for the first time, kidney stones were successfully fragmented within a patient’s body by externally generated shock waves. The mechanical energy of shock waves was transmitted through the intact skin and concentrated on the stone without significant damage of the tissue. The granular fragments were flushed out of the body in natural way, eliminating the need for invasive surgery. This date marks the beginning of a new era characterized by application of acoustic energy for non-invasive stone fragmentation and clearing **(1)**
The revolutionary finding was that shock waves may pass through living tissue without significant injury or side effects while being simultaneously strong enough to fragmentize hard urinary stones.
The key reasons are the following: first, elasticity of living tissue, which may pass high transient pressures up to 100 MPa (1,000 bars) and more; second, the possibility to couple acoustic energy with low intensity into the body and concentrate (focus) it on the region of interest, the stone to be fragmented. **(1).**
To achieve optimal coupling, the patient was placed in a large basin filled with degassed, deionised water and known as ‘‘the most expensive bathtub in the world.’’ Because these initial procedures were very painful, they had to be conducted under general anaesthesia. Further technical developments made the machines more user friendly and the treatments less painful. Coupling is now achieved through a water filled cushion covered with ultrasound jelly. In addition, by modifying the shock wave generators, the treatment has become less painful, and analgesia rather than anaesthesia is usually sufficient **(2).**

Parts of shock wave lithotripsy devices: -

(1) Shockwave generator.
(2) Coupling mechanism.
(3) Focusing system
(4) Localization system.

Shock wave generator:

A. Electrohydraulic Shock Wave Generation: -

Shock waves may be generated by explosive processes, primarily, expanding faster than the speed of sound in a particular medium such as water. Instead of explosive material, the first clinically used method was based on a high-energy electrical discharge across a 1-mm spark gap ignited in a water bath. A capacitor bank was charged by

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approximately 20,000 V (20 kV) and discharged across the electrode generating a rapidly expanding plasma channel (spark). This plasma channel pushed the surrounding water by pressures of more than 100 MPa, which propagated into the medium **(3).**

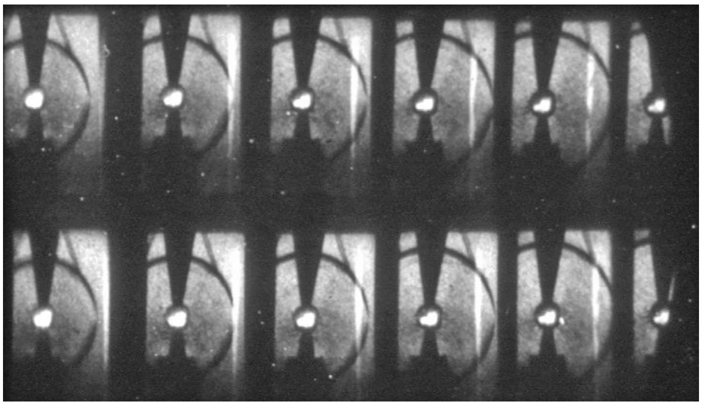

Figure (1): photography of spark and shock wave generated in water
(10 7 frames/s). A spark is ignited between two electrode tips in a distance of approximately 1 mm.

The primary shock wave generated by this method is a spherically expanding wave, which propagates with the speed of sound into the surrounding medium. The energy is dissipated by expansion and needs to be concentrated on the target stone for fragmentation. Concentration is done by reflection of the spherical wave at the surface of a hollow ellipsoidal metal reflector The spark gap is placed at the first focal spot of the ellipsoid, and the primarily diverging wave is concentrated at the second focal point in a distance. By cutting the ellipsoidal structure at an intermediate level, this second focal spot can be placed outside the metal structure to be aimed from outside the human body at the target stone within the body**(3).**

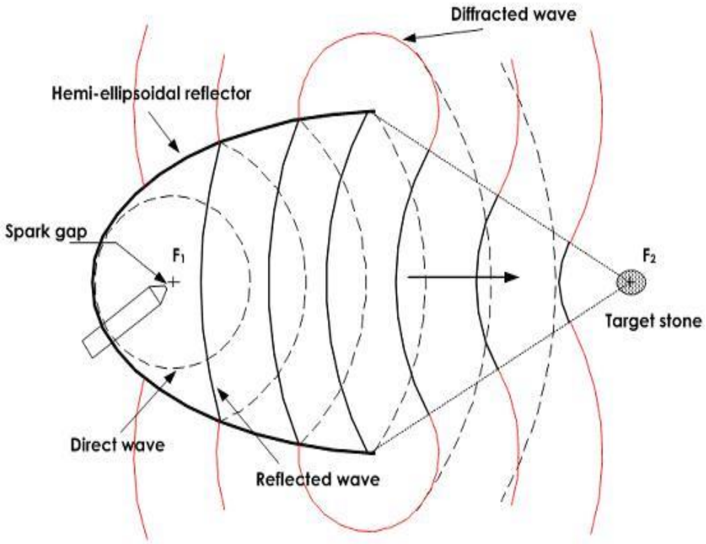

Figure (2): Spherical shock waves generated in the first focal spot *F1* of a semi-ellipsoid are partly concentrated on an area around *F2* , the second focal spot of the ellipsoidal structure. Part of the primary spherical wave is radiated as dissipating wave without being focused

B. Piezoelectric Generator:-

Shock wave generation is based on the piezo effect, which is widely used in ultrasound diagnostic devices. Making use of the piezo effect, a large number of piezo ceramic elements are activated simultaneously by electrical excitation, the

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elements expand, and the displacement of the surface generates a pressure wave that propagates into the adjacent medium **(3).**

The piezoelectric effect produces electricity via application of mechanical stress. The Curie brothers first demonstrated this in 1880. The following year, Gabriel Lippman theorized the reversibility of this effect, which was later confirmed by the Curie brothers. The piezoelectric generator takes advantage of this effect. Piezoelectric ceramics or crystals, set in a water-filled container, are stimulated via high-frequency electrical pulses. The alternating stress/strain changes in the material create ultrasonic vibrations, resulting in the production of a shockwave **(4).**

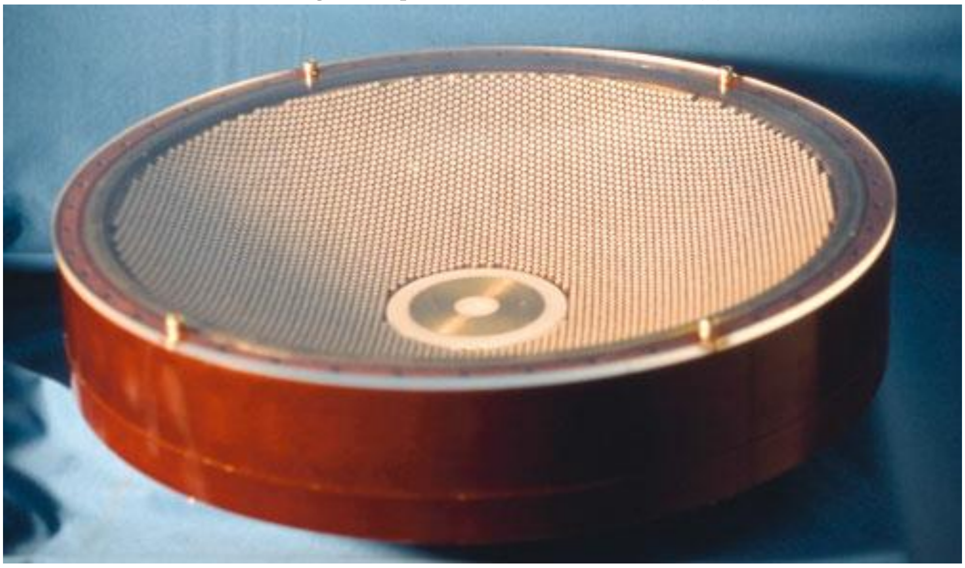

Figure (3): Piezo-calotte. Numerous piezo elements are arranged on a spherical bowel and activated simultaneously to generate a self-focusing spherical pulse wave **(3).**

C. Electromagnetic Generator:-

This vibration is then transferred to a wave-propagating medium (i.e., water) to produce Shock waves. The heart of this system is a cylindrical coil. The cylindrical membrane is pushed away from the coil. The cylindrical membrane is pushed away by the induction of a magnetic field and accelerated radically outwards by a pulsed current, thus initially generating a cylindrical wave perpendicular to the cylinder axis **(3).**

This generators will deliver several hundred thousand shock waves before servicing, thereby eliminating the need for frequent electrode replacement **(5).**

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Figure (4): Cylinder source. The electrical cylinder coil is covered by an insulation foil and a conducting membrane.
(Quoted from Shock Wave UA 2019 shock wave therapy conference invitation)

Coupling mechanism:-

It is important to establish a bubble-free and permanent coupling between the shock wave generator and the patient's body. Even small bubbles of air increase impedance and lead to the significant reduction of shock wave energy levels. Therefore, check repetitively for a bubble free environment before and after major patient movements. Coupling is warranted using oil on the generator that is attached to the table membrane. The patient is positioned on top of the table membrane and warm water is added to optimize the contact between generator and patient When using ultrasound gel, it must also be freed from air bubbles, because this leads to a decrease in treatment efficiency by up to 25% **(6)**

The best technique was to dispense a large volume of gel directly from a stock jug onto the lithotripter water cushion, as opposed to gel application by hand . The gel was then allowed to spread during stepwise inflation of the lithotripter water cushion. These techniques resulted in significantly fewer coupling defects compared with application of gel by hand, although clinical application of these techniques could prove difficult **(7)**.

Focusing systems:-

converge at the second focal point (F2). The target zone, or blast path, is the 3- dimensional area at F2, where the shockwaves are concentrated and fragmentation occurs. **(8).**

Focusing systems differ, depending on the shockwave generator used. Electrohydraulic systems used the principle of the ellipse; a metal ellipsoid directs the energy created from the spark-gap electrode. In piezoelectric systems, ceramic crystals arranged within a hemispherical dish direct the produced energy toward a focal point. In electromagnetic systems, the shockwaves are focused with either an acoustic lens (Siemens system) or a cylindrical reflector (Storz system) **(9)**.

Localization system: -

Locating the Stone in Different Axes, Table mobility is classified in x-, y-, and z-axis. Movement towards head and feet is defined as x-axis while lateral movement towards right and left is defined as y-axis and Vertical table movement is defined as z-axis**. (10).**

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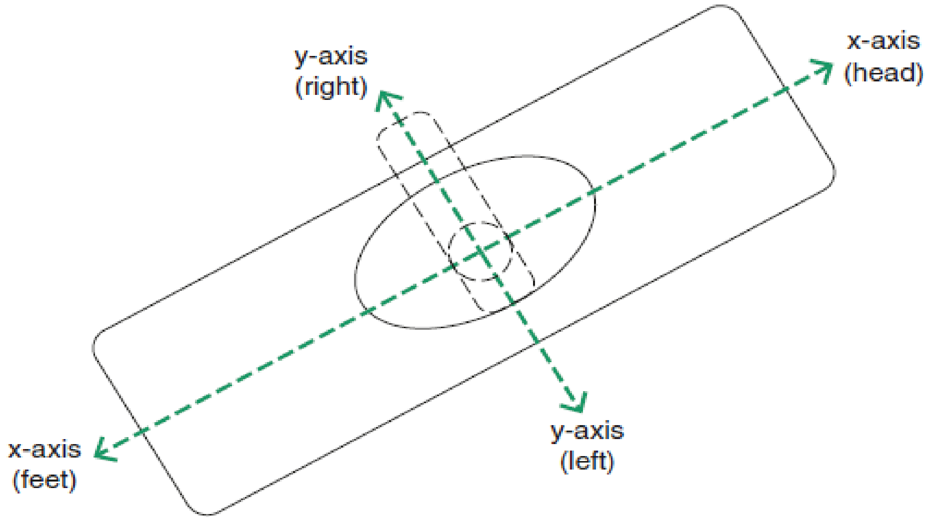

Figure (5):(10).(Defining x- and y-axis)

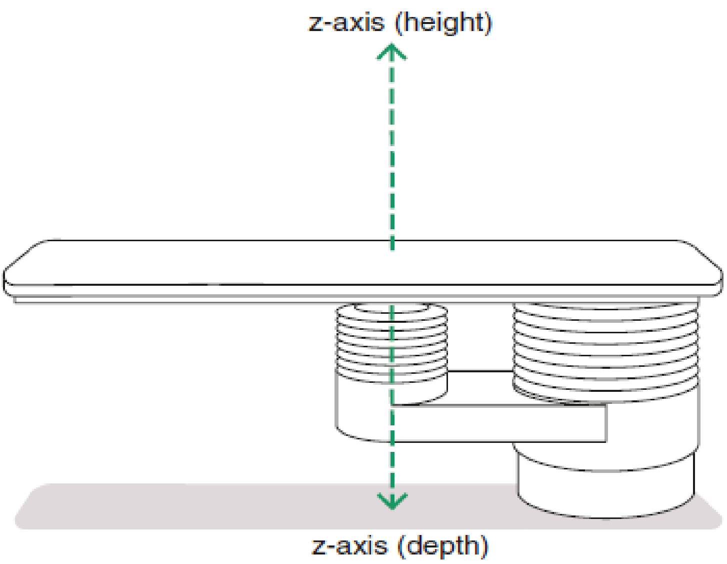

Figure (6):(10).(Defining z-axis)

Prerequisite for a successful treatment is the safe and correct stone localization in both, the 0° and 30° camera position.

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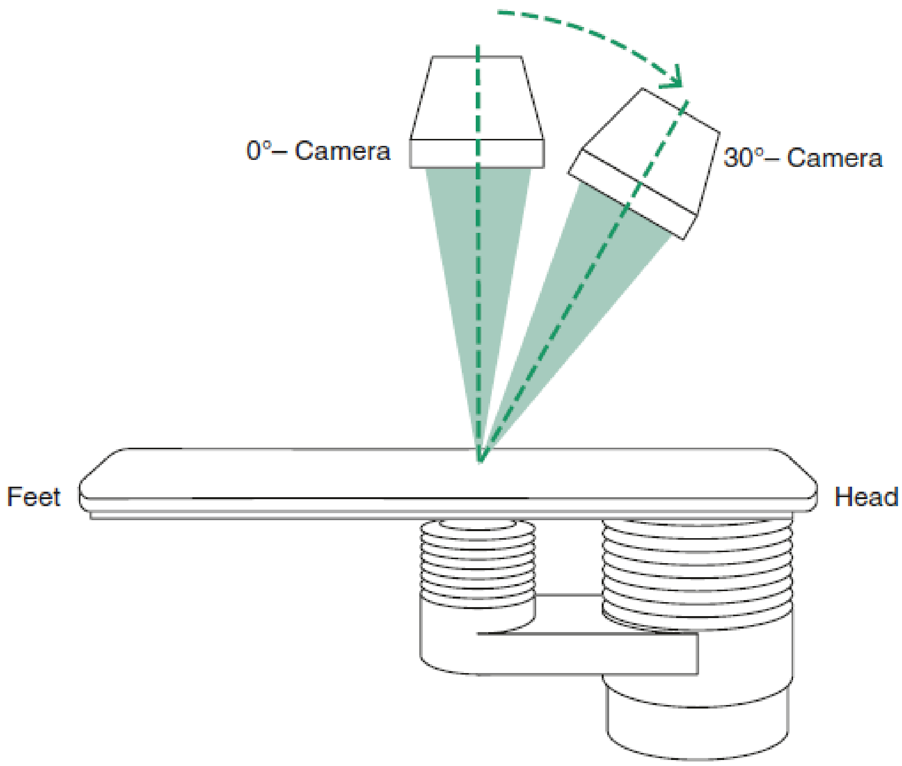

Figure (7):(10).(Camera position in 0° and 30)°

The localization approach starts within the 0° projection. The goal is to position the stone in the centre of the focus by adjusting all three dimensions x-axis (left-right), y-axis (head-feet) and z-axis (height-depth). Using fluoroscopy, the stone is first brought into position in the x-axis (arrow 1), in this example by moving the table into feet direction. This is followed by correction of the y-axis (left-right, arrow 2). To finally position the stone in the z-axis (height-depth, arrow 3) adjustment is made in the 30° projection and the stone is then centred into the treatment focus, in this example by raising the table level, Safe and precise stone localization in the 0°–30° plane is a basic requirement for successful SWL. Be aware of the different geometric views in the different projections.**(10).**

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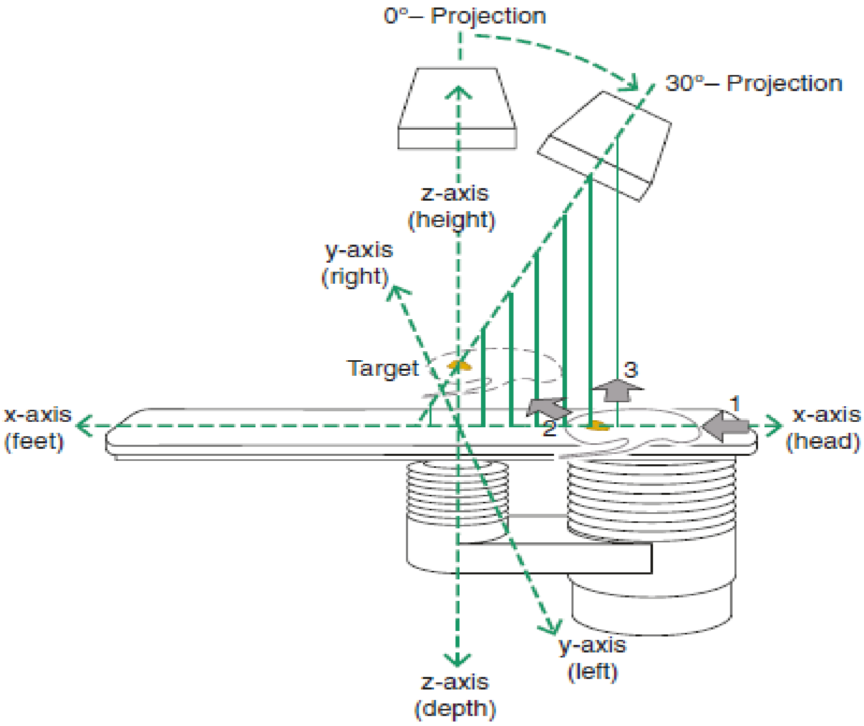

Figure (8):(10).(Positioning of the stone into the focus)

Fluoroscopy is the current standard for stone localization. Although the original Dornier HM3 was expensively equipped with two x-ray systems installed at a 90 angle, modern machines have the fluoroscopy unit mounted on an isocentric C-arm **(11).**

Factors such as high body mass index, pronounced medial orlateral stone positions, partial overlapping by bony structures,or complicating factors such as phleboliths, overlapping byintestinal gas, or anatomical anomalies may complicate localizationconsiderably. Therefore, trial detection prior to anaesthesiaand therapy can sometimes be useful in order toprepare suitable corrective measures in advance.Possible measures for the optimization of stone detection inthe 30° plane are: compression belts and wedges, lifting or loweringof the table membrane, and lifting or lowering of thecoupling cushion. **(10).**

Ultrasound:

and only kidney and distal ureteric stones can be visualized. Stones can also be obscured by an indwelling ureteric stent **(11).**

Combined systems:

for lithotripsy but also for a broad range of endo-urologic applications **(12).**

Contraindications of ESWL: -

1. SWL in pregnancy has been associated with low birth weight, placental displacement, miscarriage, and therefore the procedure is contraindicated. **(10)**
2. aortic aneurysms pose a bleeding risk for patients undergoing SWL and classically, are included in the list of contraindications. The literature, however, is mixed on the safety of SWL in patients with aneurysms, with some case reports outlining complications, while other documents safe treatment **(13).**
3. Uncorrected bleeding diathesis more common risk factor for bleeding is patients with a bleeding diathesis and use of anti-platelet, antithrombotic or anticoagulant medications, particularly when the kidney is included in the blast-path of SWL treatment (i.e., for renal and upper ureteral stones)**(14)**

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4. Hypertension is another significant risk factor for bleeding post-SWL. Untreated or severe hypertension is an absolute contraindication as multiple studies have linked this to increased bleeding and perinephric hematoma **(15)**
5. Bacteriuria is a common finding among patients with infected stones, catheters, nephrostomy tubes and the elderly, Urinary tract infections are a common complication seen in up to 5% of patients undergoing SWL Pyelonephritis or sepsis are rarer, but are possible, particularly if patients with untreated bacteriuria or untreated urinary tract infection undergo SWL **(16)**
6. **In severe obesity**, skin–stone distance can exceed the penetration depth of the shock wave or patient weight can exceed manufacturer specifications for safe load of the table **(17).**

Anaesthesia and Analgesia in ESWL: -

In principle, SWL can be performed in patients under either anaesthesia (spinal, peridural or tracheal intubation) or analgesia.Successful treatment is generally based on shock waves hitting the desired target. Pain will lead to patient movements, which may result in shock waves hitting surrounding tissue rather than the stone. Anaesthesia reduces this problem

and, furthermore, permits the application of highest energy levels if necessary. Pain also leads to increased breathing movements, which may again decrease the precision and efficacy of each individual shock wave. **(10).**
Though analgesic treatment may help to reduce such problems, it is not nearly possible to use comparable maximum energy levels as it is in patients under anaesthesia. In addition, X-ray settings must be controlled more often and/or reset completely in cases of extended treatment duration and in patients with declining analgesic efficacy, which may
increase fluoroscopy and total treatment times. Moreover, the location of the stone and the scheduled treatment duration also are important variables of decision-making. **(10).**

Benefits of treatment under anaesthesia	Benefits of treatment under analgesia
Less patient movements ⇒ More shock waves in target	No anaesthetic risks
More consistent breathing movements ⇒ More shock waves in target	
Higher maximum energy levels	
Entire therapy in one session	
Possibly: shorter fluoroscopy times	
Possibly: shorter treatment duration	

Table (1): Benefits of treatment under anesthesia compared to analgesia **(10).**

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