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Cavitation role in extracorporeal shock wave lithotripsy

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This paper presents a study of the role played by cavitation role in the disintegration of urinary calculi generated by a modified extracorporeal shock wave lithotripsy (ESWL) system. The ElectroMagnetic Acoustic Source of a Lithostar lithotripter initiated the incident shock waves into the water, and the ultrasound transducer fixed into the system played an important role by enhancing the cavitation effects of the bubbles in the Calcium-silicate target fragmentation.

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1. Introduction

Extracorporeal shock wave lithotripsy (ESWL) is the use of high-energy shock waves to fragment and disintegrate kidney stones. The shock wave, created by using a high-voltage spark or an electromagnetic impulse, is focused on the stone. This shock wave shatters the stone and this allows the fragments to pass through the urinary system. Since the shock wave is generated outside the body, the procedure is termed extracorporeal shock wave lithotripsy, or ESWL.

Lithotripsy uses the technique of focused shock waves to fragment a stone in the kidney or the ureter. The patient is placed in a tub of water or in contact with a water-filled cushion, and a shock wave is created which is focused on the stone. The wave shatters and fragments the stone. The resulting debris, called gravel, then passes through the remainder of the ureter, through the bladder, and through the urethra during urination. There is minimal chance of damage to skin or internal organs because biologic tissues are resilient, not brittle, and because the shock waves are not focused on them.

Current generators use either electro-hydraulic, piezoelectric or electromagnetic elements to produce energy which is then directed skin onto the stone through the skin under x-ray or ultrasound guidance. The stone is disintegrated in situ and the patient left to pass the fragments over the next days or weeks. Most treatments are performed as an outpatient procedure under local anaesthesia or sedation+analgesia [1].

The extracorporeal shock wave lithotripter is a generator of mechanical shock waves, which are generated outside the human corpus and have the capacity to disintegrate urinary calculi.

The generation of large cavitation bubbles is one of the most important areas of investigation in the search to improve the efficiency of extracorporeal shock wave lithotripsy; therefore the possibility of an enlargement of the induced cavitation size must be investigated. The stresses generated at large bubble implosion are larger than those generated during incidence of the primary shock wave. The most prominent advantage in comparison with other classical surgery techniques is that no stone contact is necessary in the stone pulverisation.

When a shock wave generated by an extracorporeal shock wave lithotripter interacts with a solid, it can produce cavitation bubbles at the interface between the solid and the surrounding liquid. The implosion of the cavitation bubbles plays an important role in the disintegration of renal calculi [2], [3]. The generation of large cavitation bubbles is one of the most important areas of investigation in the search to improve the efficiency of extracorporeal shock wave lithotripsy; therefore the possibility of an enlargement of the induced cavitation size should not be ignored. The stresses generated at large bubble implosion are larger than those generated during incidence of the primary shock wave [3].

2. ESWL description

The extracorporeal shock wave lithotripter is a generator of mechanical shock waves. Such waves are generated outside the human corpus and have the capacity to disintegrate urinary calculi. The most prominent advantage in comparison with other techniques is that no stone contact is necessary in pulverisation the stone.

A large, plane wave is generated by an ElectroMagnetic Acoustic Source (Fig. 1) and is focussed, by means of an acoustic lens on the stone position. The high-tension supply charges the high-voltage capacitor to a pre-defined voltage (14 kV to 21 kV).

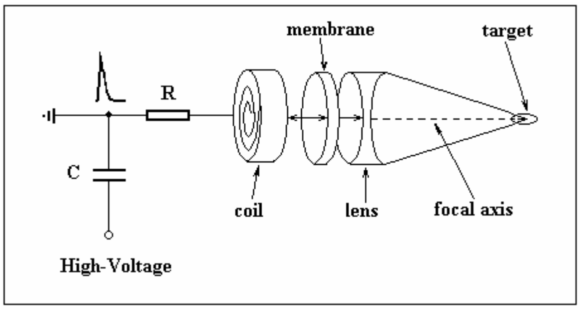

Fig. 1. ElectroMagnetic Acoustic Source for ESWL.

The current pulse in the coil (within the lithotripter) is generated by the discharge of the capacitor. This electrical current produces a rapidly increasing magnetic field, which induces eddy currents inside the homogeneous membrane. The eddy currents produce an inverse magnetic field, and the membrane is repelled, transmitting a shock wave into the water. The acoustic lens focuses the shock wave on the stone position. The shock wave is measured at the stone wave by means of a P.V.D.F. – sensor (Poly-Vinyl Difluoride). This signal is visualised on a digital oscilloscope (Fig. 2).

3. Experiment description

Using an experimental system that mimics stone fragmentation we have investigated the role of stress waves and cavitation comminution in extracorporeal shock wave lithotripsy (ESWL). Small Calcium-silicate plate samples of 10 mm thickness were exposed to shock waves generated by ESWL.

To study the cavitation bubble formation process by the ESWL shock wave under different ultrasonic field characteristics, an ultrasonic piezoceramic sandwich traducer (UPT) has been designed and manufactured [4]. The UPT converts the electrical oscillations from a signal power generator in mechanical vibrations, and the ultrasonic waves propagate into the water till the target. The metallic horn radiator concentrates and amplifies the ultrasonic energy.

The ElectroMagnetic Acoustic Source of lithotripter generates shock waves into water, and an ultrasound transducer mounted inside system provided an important role by enhancing the cavitational effects of the bubbles in the fragmentation of a Calcium-silicate target. The experimentations were performed using a photo camera, at 200 μsec delay time of shuts, 50 pulses number of burst signal and 1 sec time period of burst signal.

It was utilised montage from Fig. 2, with the experimental transducer put in the Lithostar into a water tank, and supplied by the Pulse/Function Generator.

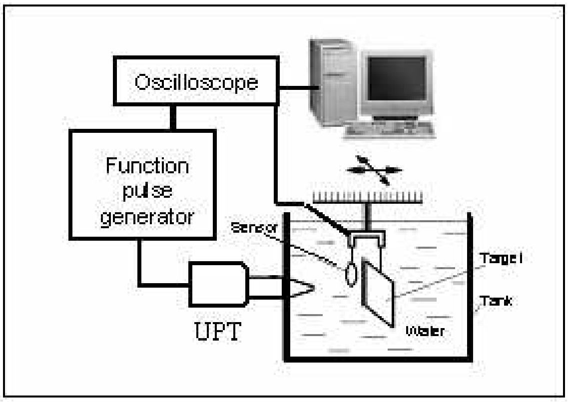

Fig. 2. Set-up for parameter measurement of UPT transducer with radiator into water tank.

The experimentations were performed in the same conditions, such as: 200 μsec delay time of photo camera shuts, 50 pulses number of burst signal and 1 sec time period of burst signal. The cavitation bubbles cloud generated by the modified ESWL system is presented in Fig. 3.

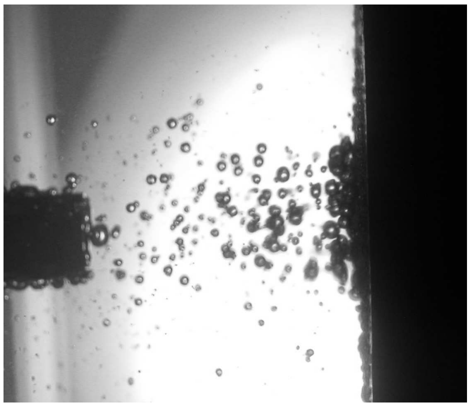

Fig. 3. Cavitation bubbles generated by the modified ESWL system.

4. Conclusions

The ESWL system with ultrasonic transducer proved enhanced efficiency in the fragmentation of ceramic material targets, by increasing the number of burst signals and shocks, decreasing the work time and increasing the size of cavitation bubbles. It is concluded that, although stress wave-induced fracture is important for the initial disintegration of kidney stones, cavitation is necessary to produce fine passable fragments, which are most critical for the success of clinical ESWL. Stress waves and cavitation work synergistically, rather than independently, to produce effective and successful disintegration of renal calculi in ESWL [5].

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