Innovative Piezoelectric Extracorporeal Lithotripter

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INTRODUCTION

Before 1980, the majority of patients with urolithiasis and nephrolithiasis needed surgery (Kerbl, Rehman, Landman, Lee, Sundaram, & Clayman, 2002; Soucie et al., 1994). Fortunately, percutaneous nephrolithotomy, ureteroscopic intrarenal surgery, laparoscopic surgery, and extracorporeal shock wave lithotripsy (SWL) now allow almost any calculus to be removed without open surgery. SWL refers to the use of high intensity pressure pulses, generated outside the body, to break up kidney stones (Chaussy, Brendel, & Schmiedt, 1980; Loske, 2007). It has become the standard treatment for the majority of patients and an alternative in the management of gallbladder stones, pancreatic concrements, and salivary gland stones. Even though initial studies concluded that shock waves had no damaging effect on renal tissue, later several authors reported that shock waves may cause tissue trauma (Evan, Willis, Connors, McAteer, & Lingeman, 1991; Evan, Willis, & Lingeman, 2003 Willis et al., 1999). Fortunately, techniques and devices are still evolving and improvements to increase stone fragmentation efficiency and reduce tissue trauma are being constantly sought.

BACKGROUND

The apparatus to perform SWL, called lithotripters, are composed of a shock wave generator, a focusing unit, an imaging system, a coupling device, and a treatment table (Lingeman, 2007; Loske, 2007). If the patient is properly positioned, shock waves enter the body, become focused on the calculus, and fracture it. Shock wave targeting is performed by fluoroscopy or ultrasound imaging systems. Several hundred shock waves may be needed to comminute a kidney stone. Fragments pass spontaneously through the urinary tract, and most patients are free of stones a few days after treatment. Three shock wave generation techniques are in use: piezoelectric, electrohydraulic, and electromagnetic (Loske, 2007). Many lithotripters use a focusing system to concentrate the shock wave energy onto the stone; others are self-focusing. Only piezoelectric shock wave generation will be discussed here.

Piezoelectric lithotripters generate shock waves by a high voltage discharge applied across an array of up to 3000 piezoelectric crystals mounted on a hemispherical bowl-shaped aluminum backing (Figure 1). Other systems only use a few crystals or one large spherically shaped ceramic plate. Each high voltage discharge causes rapid expansion of each crystal, producing a pressure wave. The pressure pulse arriving at the center (F) is generated by superposition of the pulse produced by each crystal (Loske, 2007). The shock wave generator is contained inside a cavity filled with water and closed with a rubber membrane placed in contact with the skin of the patient. Piezoelectric crystals are insulated from water with a flexible polymer. These lithotripters produce a focal zone in the shape of a cigar measuring about 17 × 3 mm. The shock wave pulse rate and the discharge voltage can be varied. The pressure in the focal region (Figure 2) consists of a compression pulse with a peak between 30 and 150 MPa and a phase duration of 0.5 to 3 μs, followed by a decompression pulse, sometimes referred to as the "negative" pressure pulse, with a tensile peak of up to - 20 MPa, and a phase duration between 2 and 20 μs. Pressure rise time is about 300 ns.

Cavitation is one of the main stone comminution mechanisms. Calculi also fracture due to spalling, squeezing, superfocusing, and fatigue (Eisenmenger,

Figure 1. Schematic of a standard piezoelectric shock wave generator. The power supply P charges a capacitor C, which remains charged until the switch S is fired by the trigger T. Shock wave rate can be adjusted with the pulse generator G.

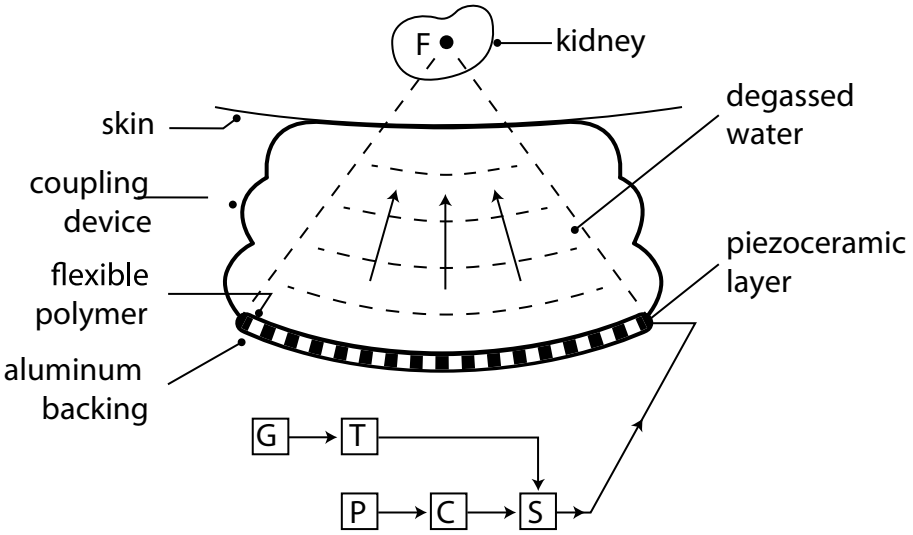
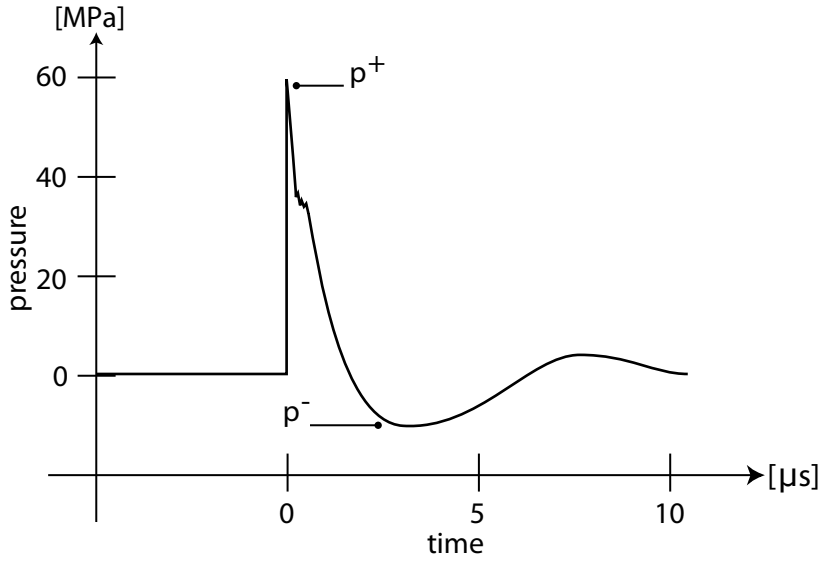


Figure 2. Pressure record obtained with a fiber optic hydrophone (FOPH 2000, RP Acoustics, Leutenbach, Germany), positioned at the focus of a standard piezoelectric lithotripter.



2001; Lokhandwalla, & Sturtevant, 2000; Loske, 2007). During SWL, all microbubbles contained in the fluid near the calculus are compressed by the positive peak (Figure 3). Their volume increases about 50 to 100 µs after shock wave passage. This occurs due to the action of the tensile part of the shock wave (Bailey et al., 2005). Lithotripter generated bubbles expand, stabilize, and collapse violently after approximately 250 to 500 µs, producing high-speed microjets (Crum, 1988), capable of damaging the calculus.

Enhanced fragmentation can be obtained if a second shock wave arrives during or shortly after their stable phase (Figure 4). This has been demonstrated with twin pulses generated from two identical shock