The Characteristics of Broad and Narrow Focal Zone Lithotripters

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The Characteristics of Broad and Narrow Focal Zone Lithotripters

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Abstract. The focal width of a lithotripter is a measure of the diameter of its focal zone, the region where acoustic pressures are at least half the maximum positive pressure generated at a given power level. Different lithotripters have different focal widths. The Dornier HM3, for example, has a focal width of ~10-12mm and for many years this was the widest focal zone among clinical machines. Electromagnetic lithotripters tend to have narrower focal zones, in the range of ~4-6mm. Recent studies suggesting that focal width plays an important role in stone breakage prompted this assessment of two electromagnetic lithotripters. Acoustical mapping using a fiber optic probe hydrophone (FOPH-500) and breakage of U-30 gypsum model stones were used to compare a conventional lithotripter (Dornier DoLi-50) and a broad focal zone device (XiXin XX-ES). FOPH mapping characterized the focal width of the DoLi to be about 5mm and that of the XX-ES to be much wider (~18mm). For stone breakage experiments the DoLi was fired at power level 3 (mid-range) and the XX-ES was operated at the recommended clinical setting of 9.3 kV. Both lithotripters were fired at 60 SW/min. U-30 model stones held in a 2mm mesh basket were positioned at the clinical target point on the acoustic axis and at 5mm steps laterally, and the number of SW's to complete fragmentation was counted. Breakage on-axis was similar for the two machines (DoLi 676±105 SW's versus XX-ES 644±123 SW's, $p>0.6$), but at 15mm the DoLi required nearly twice the number of SW's as the XX-ES (DoLi 3006±780 SW's versus 1726±972 SW's, $p<0.006$). This demonstrates that a broad focal zone lithotripter is more effective in breaking stones off axis and supports the idea that focal width is an important feature, likely to be relevant in the clinical setting where respiratory motion may limit the effectiveness of narrow focal zone machines.

Keywords: shock wave lithotripsy, focal width, peak pressure, stone breakage efficiency.
PACS: 43.80.Vj, 43.80. Gx, 43.35.Yb.

INTRODUCTION

Lithotripters differ in the characteristics of the focal zones they generate, and the width of the focal zone can vary from quite narrow to broad (i.e. ~3-4mm for the Storz Modulith, to ~18mm for the XiXin XX-ES). Others have demonstrated in vitro that the focal width of a lithotripter can affect its stone breakage efficiency, and the effect is most evident when the stone is moving. That is, when stones were placed in a motorized device that simulated stone movement during respiratory excursion, a lithotripter with a focal width of ~12mm showed significantly better breakage efficiency than a lithotripter with a focal width of ~3-4mm [1]. In the current study we, likewise assessed the role of focal width in the effectiveness of stone breakage,

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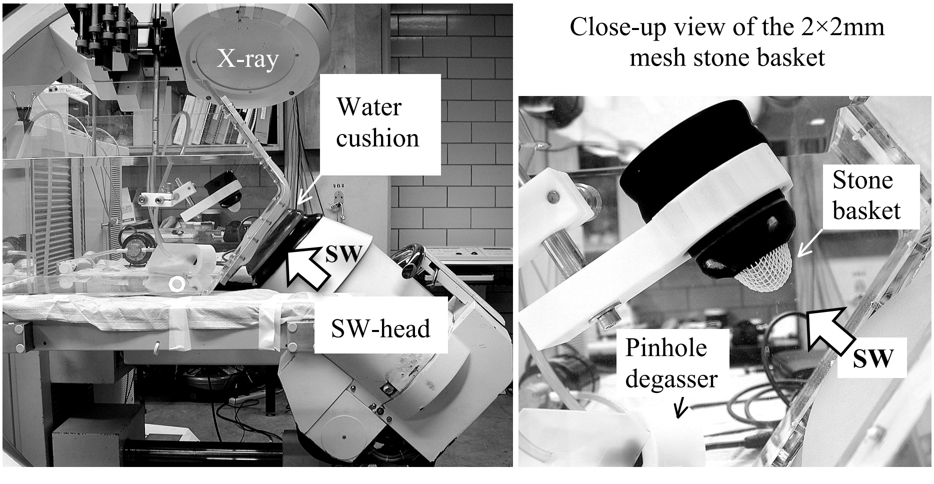
but in this case we used a static in vitro system in which the stones were purposely placed off-axis.

MATERIALS AND METHODS

This study was conducted using two clinical electromagnetic lithotripters, a DoLi-50 (Dornier MedTech America, Inc., Kennesaw, GA, USA) [2] and a XX-ES (Xi Xin Medical Instruments Co. Ltd., Suzhou, PRC) [3, 4]. The DoLi has 6 power levels and was operated at mid-range, power level 3. The XX-ES was operated at the recommended clinical setting 9.3kV. Both lithotripters were fired at 60 shock waves per minute.

The water cushion of the DoLi (Fig. 1) was coupled to the acoustic window of the test tank using LithoClear gel (Sonotech Inc., Bellingham, WA), as previously described [5]. The water cushion of the XX-ES lithotripter was submerged directly into the test tank (Fig. 2). The test tank was filled with tap water at room temperature. The water was continuously degassed using a pinhole degasser [2]. Dissolved oxygen remained at dynamic equilibrium at about 30% of saturation (or 2.7ppm).

Functional performance of the lithotripters was assessed using Ultracal-30 gypsum stones (6.5mm diameter by 7.5mm length) held in 2 mm mesh baskets (Figs. 1-2) [6]. The baskets were positioned at the clinical target point on the acoustic axis, and at 5 mm steps laterally, and the number of shock waves to complete breakage was counted. At least seven stones were broken at each position.



Close-up view of the 2×2mm mesh stone basket

FIGURE 1. Experimental setup for stone breakage with the DoLi. DoLi shock waves (SW) propagate at 45º (arrow). Model stones were broken in the 2×2mm nylon mesh basket positioned on the acoustic axis, and at 5 mm steps laterally.

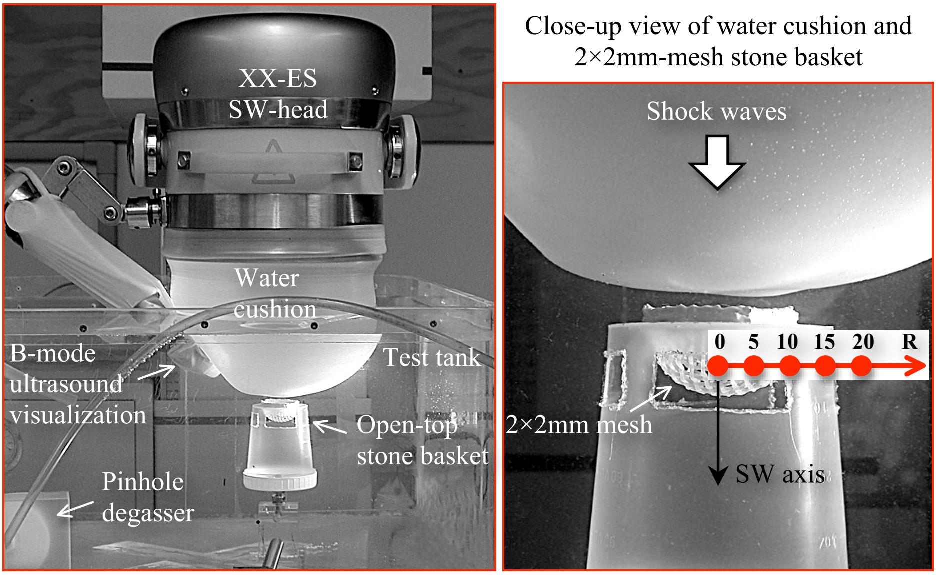


FIGURE 2. Experimental setup for stone breakage with the XX-ES lithotripter. The XX-ES shock wave head sits above the treatment table, so SWs propagate downward (vertical arrow). Model stones were broken in the open-top 2×2mm nylon mesh basket positioned at lateral distances (R) of 0, 5, 10, 15, and 20mm off-axis (right panel).

Except for differences in the physical configuration of the two lithotripters, test conditions (i.e. water quality, stone model) were very similar. Whereas the DoLi is a conventional device in which the shock head is below the treatment table (acoustic axis ~45º), the shock head of the XX-ES is above the table and SW's propagate downward (Fig. 2). As such, in stone breakage experiments with the DoLi—as is the case for typical lithotripters—SW's passed through the mesh basket to reach the stone. With the XX-ES, however, SW's impacted the stone directly from above. The potential effect of this difference in the experimental set-ups is described elsewhere in these proceedings [Pishchalnikov et al]. In that study it is shown that passage through a mesh reduces the negative tail of SW's but has virtually no effect on the positive pressure of the pulse. Therefore, we have assumed that the leading positive-pressure phase of SW's delivered to stones in mesh baskets can be characterized for both of these lithotripters using acoustic measurements performed in the free-field.

Free-field characterization of the acoustic field of these lithotripters was performed using a fiber-optic probe hydrophone (FOPH-500, RP Acoustics, Leutenbach, Germany). Waveforms were recorded in sets of 30-100 SW's collected at 1mm steps lateral to the acoustic axis in the targeting plane of the lithotripters [4]. Average temporal profiles were calculated by realigning individual SW's at the half amplitude of their shock fronts [2]. The spatial distribution of P+ was used to determine the widths of the focal zone, defined as the lateral distance at which the peak positive pressure drops by half of its maximum value measured on the acoustic axis of the lithotripter [7]. As the 50% decrease in amplitude corresponds to about -6dB on the decibel scale, the focal width is also referred as the -6dB zone of the lithotripter.

RESULTS

Lateral distributions of peak positive pressure with the DoLi and the XX-ES lithotripters are shown in Fig. 3. We assume cylindrical symmetry of the acoustic fields so the lateral distribution of P+ is shown as a function of the radial distance R from the axis. These measurements show that the focal width (or -6dB zone) was ~5mm diameter for the DoLi (Fig. 3a), and ~18mm diameter for the XX-ES lithotripter (Fig. 3b). Thus, the focal width of the XX-ES was 3.6 times wider than the -6dB zone of the DoLi.

Breakage of model stones showed that the lateral distribution of breakage efficiency fell faster for the narrow focal zone lithotripter (DoLi) than for the broad focal zone lithotripter (XX-ES), although breakage was not significantly different until 15mm lateral. At R=15mm, the DoLi required almost twice the number of SWs as the XX-ES (3006±780 SW's vs. 1726±972 SW's, $P<0.006$). The DoLi was entirely ineffective at R=20mm (no breakage with 10,000 SW's), while the broad focal zone XX-ES achieved breakage (3691±1618 SW's) even at this large distance off-axis. Thus, the broad focal zone lithotripter (XX-ES) had a broader region of stone comminution than the narrow focal zone machine (DoLi).

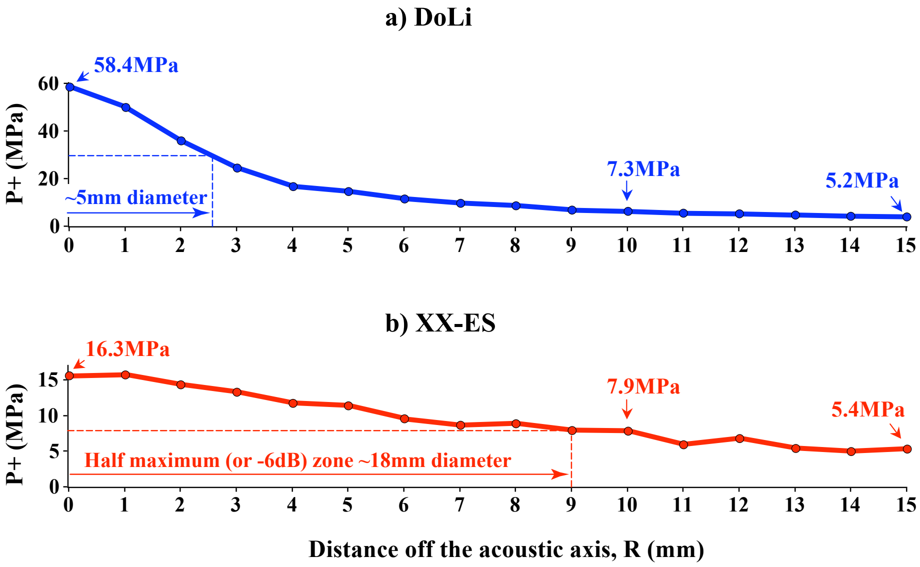


FIGURE 3. Lateral distribution of peak positive pressure (P+) with the Doli (a) and the XX-ES (b). The focal width (half maximum P+ or -6dB zone) was ~5mm diameter for the DoLi, and ~18mm diameter for the XX-ES. At the power levels used in this study (DoLi PL3; XX-ES 9.3kV) peak positive pressure on the DoLi axis (58.4MPa) was 3.6 times greater than P+ on the XX-ES axis (16.3MPa).

DISCUSSION

Several recent studies suggest that the width of the focal zone plays an important role in stone breakage. Laboratory experiments with model stones show that it takes fewer SW's to fracture a stone when the incident pulse is wider than the stone [8]. Likewise, numerical modeling has been used to demonstrate that shear stress within a stone is enhanced, and more energy is delivered to the stone interior, when the focal width is wider than the stone [9]. This, plus the finding that a wider focal zone is more effective than a narrow focal width at delivering effective energy to a moving stone, has focused attention to the potential benefit of a broad focal zone in SWL [1]. The present findings support the idea that a broad focal zone may, indeed, be an advantage. These data provide a functional correlate (stone breakage) to acoustic measurements of focal width, and show that a lithotripter with a broad focal zone is more effective at breaking stones further off axis than a lithotripter with a narrow focal width.

An obvious footnote to this study is that the waveforms of these two lithotripters exhibit somewhat different structure. That is, at its geometric focus the DoLi-50 shows a typical shock front—an instantaneous rise to maximum positive pressure with an overall duration of the compressive phase of only ~2 μs [2]. The XX-ES on the other hand has a pulse of low amplitude and long duration and only forms a true shock at the acoustic focus (distal to targeting point) [4]. Thus, the acoustic output of these two machines differs in more than just the dimensions of the focal zone. Clearly, further work is needed to determine the role of features of the waveform of these and other lithotripters in breaking stones on and off axis. Still, this is a solid indication that a broad focal zone lithotripter can deliver an effective acoustic field to a wider region than a narrow focal width machine.

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