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Recent advances in lithotripsy technology and treatment strategies: A systematic review update

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HIGHLIGHTS

- The key to SWL success lies in the proper selection of patients and attention to SWL technique.
- The three modes of SW generation vary in their efficiency.
- New treatment strategies to improve success rates and safety.
- Current evidence indicates that a wide focal zone provides more efficient fragmentation.

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ABSTRACT

Introduction: Shock wave lithotripsy (SWL) is a well – established treatment option for urolithiasis. The technology of SWL has undergone significant changes in an attempt to better optimize the results while reducing failure rates. There are some important limitations that restrict the use of SWL. In this review, we aim to place these advantages and limitations in perspective, assess the current role of SWL, and discuss recent advances in lithotripsy technology and treatment strategies.

Methods: A comprehensive review was conducted to identify studies reporting outcomes on ESWL. We searched for literature (PubMed, Embase, Medline) that focused on the physics of shock waves, theories of stone disintegration, and studies on optimising shock wave application. Relevant articles in English published since 1980 were selected for inclusion.

Results: Efficacy has been shown to vary between lithotripters. To maximize stone fragmentation and reduce failure rates, many factors can be optimized. Factors to consider in proper patient selection include skin – to – stone distance and stone size. Careful attention to the rate of shock wave administration, proper coupling of the treatment head to the patient have important influences on the success of lithotripsy.

Conclusion: Proper selection of patients who are expected to respond well to SWL, as well as attention to the technical aspects of the procedure are the keys to SWL success. Studies aiming to determine the mechanisms of shock wave action in stone breakage have begun to suggest new treatment strategies to improve success rates and safety.

1. Introduction

The introduction of shock wave lithotripsy (SWL) in 1980 revolutionized the management of kidney stones. Within ten years, it became the most common intervention for patients [1] suffering from renal or ureteral calculi. The changes in SWL technology over the past 3 decades have resulted in varied success rates. Accordingly, researchers have developed a well defined range of uses for SWL to better – optimize results and reduced retreatment rates. Although ureteroscopy is gaining popularity with its recent advances, SWL remains a commonly used treatment option [2].

Abbreviations: Shock wave lithotripsy, SWL; Computed Tomography, CT; Body Mass Index, BMI; Second Focus, F2; Skin to Stone Distance, SSD; Percutanous nephrolithotomy, PCNL; Hounsefield Unit, HU; Ureteropelvic junction, UPJ; Electromagnetic lithotripter, EML.

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2. Shock wave generation

The Dornier HM3 was the first lithotripter to be widely utilized in clinical practice. It is a device that features a large water bath for optimum shock wave coupling, fluoroscopic imaging, an ellipsoid reflector with a small aperture and an electrohydraulic shockwave generator [3]. Shock wave sources have evolved over time. There are currently three types of shock wave generators: electrohydraulic, electromagnetic, and piezoelectric.

Electrohydraulic generators are based on spark – gap technology that produces a vaporization bubble. The bubble expands and immediately collapses, producing a high – energy pressure wave. The shock wave then encounters an ellipsoid reflector that focuses the wave [4].

Electromagnetic generators produce a magnetic field. The coil, which is basis of this technology, is located in one of two places: around a cylinder, on the inside plane of a spherical cap, or on a flat exterior with an overlying conductive membrane. A shock wave is produced when the magnetic field causes repulsion of the membrane. It is focused with a parabolic reflector or acoustic lens [5,6]. Unlike electrohydraulic technology, which requires electrode replacement every several thousand shockwaves, electromagnetic generators last for millions of shock waves.

Piezoelectric generators result in the generation of a shockwave by non – linear propagation [7].

A capacitor is fired through a collection of hundreds of piezoceramic elements positioned on a reflector. Each element is focused on the same location (F2) much like a satellite dish.

3. Clinical parameters that may affect outcome of SWL

The outcomes of SWL can be enhanced in many ways. Patient selection plays an important role, and factors to consider include body habitus, stone burden, anatomical location, stone density measured by non – contrast CT, and for renal stone cases, stone to skin distance.

4. Body habitus

Poor outcomes for SWL have been attributed to obesity. Appropriately positioning patients with high body mass index (BMI) to target the stone can be challenging as the focal length of most lithotripters is in the 15 cm range. Furthermore, excess adipose tissue dampens the energy from the shock wave as it travels to F2 [8]. Ackermann and colleagues' multivariate analysis reported finding that BMI was a significant negative predictor of a stone – free outcome following SWL [9]. Portis et al. have also reported similar findings [10].

Morbid obesity may render SWL impractical or technically impossible for various reasons. Firstly, there are weight limitations on the lithotripter table or gantry. Furthermore, it may be impossible to radio – graphically target the stone. Most often, the skin – to – stone distance (SSD) often exceeds the maximum allowable focal distance of the lithotripter. In such circumstances, a blast path technique that relies on high pressures generated at a point located co – axially beyond second focus (F2) may be considered [11]. The skin – to – stone distance (SSD), as measured by computed tomography, may actually be a more important outcome predictor than BMI.

A recent study combined two parameters: SSD with a measure of stone density (Hounsfield units). The results revealed that patients with both favourable parameters had a 91% stone – free rate, while those with both unfavourable parameters had a 41% stone – free rate (Fig. 1) [12].

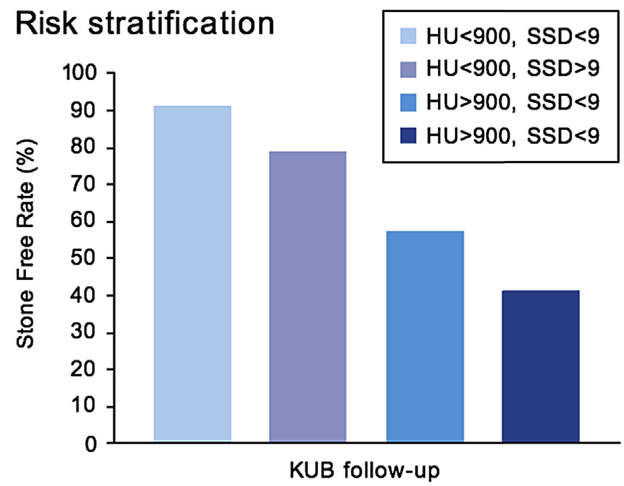

Fig. 1. Influence of stone density (HU) and SSD. HU, Hounsfield units; SSD, skin-to-stone distance.

5. Stone burden

Stone burden plays a significant role in predicting the outcome of SWL (even for patients with non – staghorn calculi). As stone size increases, the likelihood of a successful outcome decreases. EAU and AUA guidelines do not recommend SWL as primary treatment for stones larger than 2 cm in size [13,14]. These calculi are unlikely to respond well to SWL treatment, and are best managed using an alternative method, such as percutaneous nephrolithotomy (PCNL) [15].

6. Stone composition

Stones of differing composition vary widely with regard to their fragility. Similarly, stones of the same composition may respond differently to shockwaves [16]. For example, when SWL is unselectively used to treat patients with cystine stones, poor results can be expected.

Hockley and collaborators reported on 43 cystinuric patients treated with SWL and PCNL. The stone – free rates with SWL were 70.5% for calculi 20 mm or less; meanwhile, stones greater than 20 mm had stone free rates of 41% [17]. Similarly, Kachel et al. reviewed 18 patients with cystine stones and recommended SWL monotherapy for cystine stones smaller than 15 mm [18]. Chow and Streem also studied SWL treatment outcomes in 31 cystinuric patients and found an overall stone – free rate of 86.9% [19]. Hence, SWL for cystine stones should be reserved for patients with a small stone burden.

Brushite calculi also respond poorly to SWL. Klee et al. reported on 30 patients with a total of 46 brushite stones [20]. Success was defined as fragments less than 4 mm. The overall success rate for patients treated by SWL monotherapy was 65%. Hence, a reasonable treatment paradigm would recommend SWL only for patients with known brushite stones of a small size.

Poor response to SWL is not only limited to stones commonly thought of as exceptionally hard or dense. In fact, very soft matrix calculi, composed of as much as 65% organic matter (in comparison to 2% or 3% organic matter in most non – infected urinary calculi), also respond poorly to SWL [21]. When stone composition is unknown, the density of the calculus (as measured by hounsefield unit) on preoperative axial imaging can predict stone fragility and response to SWL [22].

Joseph and colleagues reported a significantly reduced stone