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SYMPOSIUM PAPER

Extracorporeal shock wave lithotripsy in the pediatric population

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Abstract Following the successful introduction for treatment of urolithiasis in adults in the early 1980s, shock wave lithotripsy (SWL) rapidly became a standard treatment for children with urolithiasis as well. SWL in children results in stone-free rates of 60–80% with contemporary equipment. Complication rates appear to be very low, although long-term risks remain uncertain. Laboratory studies in animal studies have identified deleterious effects of shock waves on renal tissue, and some have suggested that the immature or developing kidney may be more susceptible to such effects. However, clinical studies in pediatric human patients treated with SWL have not consistently identified serious long-term consequences of SWL. Therefore, despite advances in endoscopic equipment and techniques that facilitate endourologic management of pediatric urolithiasis, SWL continues to be an apparently safe and effective option in children with stones.

Keywords Nephrolithisis · Pediatrics · SWL

Extracorporeal shock wave lithotripsy (SWL) was developed in the 1960s and 1970s as an outgrowth of research on shock wave energy and propagation for both industrial and biological purposes. By the late 1970s, the Dornier corporation had developed a practical lithotripter that allowed shock waves to be focused on a solitary focal point, and after extensive in vitro and animal testing the first treatments of kidney stones in human subjects were performed in February 1980. The results of this initial series were published later that year [1], and longer follow-up of a larger series was published 2 years later [2].

Although there is no inherent reason that SWL would not be applicable to children, concerns about potential adverse effects of the technology on growing, developing bodies meant that the initial treatments in children were not conducted for several years. Nevertheless, as the success and safety of SWL in adults became evident, the attractiveness of a minimally invasive option for stone management in children eventually led to initial trials in pediatric patients. By the mid-1980s, the first publications were reporting excellent results with SWL in children [3, 4], and the technique rapidly became widely accepted as the standard of care for pediatric stone disease [5].

In recent years, advances in endourologic technologies, and the resulting transformation of urolithiasis management, have led to speculation that the long reign of SWL may be ending, even for pediatric patients [6]. It is, therefore, appropriate that we review the current state of pediatric SWL, and assess the outcomes for this modality in the contemporary era.

From the beginning, defining and measuring outcomes after SWL have been a source of controversy and debate. When we treat a patient with a kidney stone, we typically seek to render the patient "stone-free"; that is, we want the calcifications to be completely eliminated from the patient's urinary tract. However, defining "stone-free" has proved more challenging that one might expect. The varying definitions used by investigators mean that meaningful comparisons of outcomes become difficult, if not impossible. Certain studies, for example, have used plain abdominal radiographs for assessment of the post-operative stone

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burden, while other studies use CT scans. Obviously, these imaging modalities have dramatically different sensitivities for urinary tract stones, with similarly different outcome results. Many papers use concepts such as "clinically significant residual stones" as the measure of success or failure, meaning that a patient does not have to be truly "stone free" to be counted as a success. Of course, the definition of "clinically significant" itself varies widely among investigators, with different thresholds of stone size or count. Another widely used outcome measure is "re-treatment rate", but of course the decision to pursue re-treatment is highly dependent on both clinician and patient and may not reflect a reliable or objective stone burden.

Another problem with the assessment of SWL effectiveness is that of technology creep. SWL technology and equipment have continuously evolved since the introduction of the Dornier HM-3 in the early 1980s. This means that SWL studies have been conducted using a wide range of machines of different eras and manufacturers. Although all lithotripters have continued to operate on the same basic four principles (shock wave generator, shock wave focusing, shock wave coupling, and localization/imaging), the often significant differences among machines make comparisons difficult. Furthermore, the inherent delay from the time of clinical treatment to research publication means that, by the time the paper is finally published and available for review, the lithotripter(s) used in the clinical series may have become obsolescent, or may not be available (this is true, for instance, for the HM-3 which is no longer manufactured).

Nonetheless, despite these challenges we can still get a general sense of the effectiveness and safety of pediatric SWL therapy through a review of the existing literature, and in this review we will seek to do this.

The obvious question that comes up regarding pediatric SWL is whether treatment of children with SWL differs from that in adults in any meaningful way. Various authors have proposed a range of relevant differences between children and adults that might affect their response to SWL treatment. These have included suggestions that: children pass stone fragments more easily; stones in children fragment more easily; there is less tissue between coupling medium and stone; and localization of stones is easier in children due to smaller body size.

In truth, there have been a very few direct comparisons of pediatric versus adult SWL outcomes, and in the one such comparison of which we are aware, the stone-free, retreatment, and complication rates were the same between the adult and the pediatric patients, although fewer shocks were needed for the children, and energy settings were lower [7].

The initial reports of pediatric SWL using the Dornier HM-3 reported consistently high success rates of over 85%, and some studies claimed up to 100% success [3, 4, 8]. A compilation of data on 194 patients from 7 studies published between 1986 and 1989, all treated on the HM-3, finds an overall stone-free rate of 80% (range 70–92%), and retreatment rates from 8 to 40% [3, 4, 8–12].

Over time the number of available types and make of lithotripters have expanded, and the range of results has similarly widened. Examples of contemporary series have included that of Myers et al. [13] whose 445 children were treated on a Siemens Lithostar with a stone-free rate of 68%, with retreatment required in 14%. Aksoy et al. [14] achieved a stone-free rate of 86–90% on a Dornier MPL-9,000, while Defoor et al. [15] treated 88 children using a Dornier Compact Delta with 68% stone-free (74% after 2 treatments). Other reported pediatric series have usually shown similar ranges.

Management of children with urolithiasis involves circumstances that are largely specific to the pediatric population. For example, infants pose special challenges from both therapeutic and anesthetic standpoints. Infants often require multiple treatments. Lottmann et al. [16] treated 19 infants aged 5–24 months on a Technomed Sonolith or Direx Nova with a 53% stone-free rate, but this increased to 95% after two sessions. Similarly, Ramakrishnan et al. [17] treated 74 infants on a Wolf Piezolith with 88% stone-free, although 35% needed retreatment; obstruction or UTI occurred in seven children (5%). Even premature infants can be treated effectively. Shukla et al. [18] reported a series of eight premature infants aged 9–15 months on a Dornier HM-3, with 100% stone free.

Another common scenario among pediatric stone patients is concurrent anatomic or functional urological disease. Hydronephrosis, vesicoureteral reflux, or bladder dysfunction may alter urinary drainage sufficiently to affect stone clearance, and indeed in a review of the author's institution's experience we observed stone-free rates of 13% for those with, versus 67% for those without, anatomic risk factors [19]. Similarly, Tan et al. [20] reported 32 versus 65% stone-free with and without anatomic risk factors. These results suggest that, children with concurrent urological issues, such as UPJ obstruction, reflux, or neurogenic bladder may best be treated with endourologic approaches to urolithiasis.

Even large stones are often treated with SWL in children, with sometimes surprisingly good results, supporting the oft-repeated bromide that the pediatric upper tract can accommodate and pass relatively larger stones than that of adults. Shouman et al. [21] treated 24 children with stones >25 mm. They achieved a stone-free rate of 83% using a Dornier DoLi S, although they noted 4 instances of steinstrasse—ureteral obstruction due to impaction of a string of stone fragments—and 2 of lesser colic, of whom 1 patient required hospitalization. Similarly, Orsola et al. [22] treated

15 children with staghorn stones on a Siemens Lithostar and achieved 73% stone free after 1 or more sessions. Ureteral stent placement may facilitate stone passage in such children; Al-Busaidy et al. [23] treated 42 children with staghorn stones and found that stented patients had fewer complications (0 vs. 21%), although all patients did relatively well.

With respect to acute complications, SWL appears to be tolerated remarkably well by most pediatric patients. A recent compilation of almost 1,900 children who underwent SWL found that the most common complication was hematuria, reported in 8% of patients [24]. Other, more significant complications were consistently in low single digits, including steinstrasse (1.6%) or other obstruction (0.9%), colic (3%), and infection with or without fever (2.1%). Although these low proportions may represent an underestimate due to underreporting, the underlying finding (that SWL complications in children are uncommon) does appear valid.

The issue of longer term complications, and specifically the question of potential long-term effects of SWL on the developing kidney, continues to be the subject of much discussion. A recent case control study [25] that suggested a significantly higher incidence of diabetes mellitus in adult patients with a history of SWL received much attention, but subsequent analyses have failed to confirm this association [26]. Nonetheless, numerous laboratory studies have demonstrated that shock waves can have permanent detrimental effects on renal and other tissues, with resulting pathological phenomena including tubular atrophy, thickening of Gerota's fascia, renal fibrosis, decreased renal plasma flow (RPF), and glomerular filtration, as well as hypertension and proteinuria. A full discussion of this literature is beyond the scope of this review, but we will briefly review some of these data, specifically addressing whether the pediatric kidney is more susceptible to such injuries than the adult kidney.

A number of animal studies have found more significant physiologic changes after SWL in immature kidneys as compared to adults. Studies in monkeys found that RPF decreased and plasma rennin increased more in infants [27]. In rats, immature animals had greater changes in renal function and histology after SWL, but normal body and renal growth [28]. Supplementing these findings in animals, there have been a few long-term studies in human pediatric SWL cohorts suggesting a negative effect on the developing kidney. Lifshitz et al. [29] reported on 29 children with 9 year follow-up after SWL (HM-3). They compared actual renal size to expected size for age and found decreased renal length versus expected among treated kidneys. They could not distinguish between effects of SWL on kidney growth, versus intrinsic renal defects or effects of the stone disease itself. Furthermore, overall renal function was normal, and only 1 patient had hypertension. Similarly, Villanyi et al. [30] observed evidence of proximal tubular dysfunction after SWL in pediatric kidneys (increases in urine aspartate transaminase, alkaline phosphatase, LDH, and beta 2-microglobulin), but there were no changes in measures of overall renal function or serum electrolytes, and the markers of cell damage returned to baseline within 15 days.

Other clinical studies of the effect of SWL on the pediatric kidney have failed to find significant or persistent changes. Glomerular filtration rate has been shown to be stable in the initial post-treatment months [31], and out to 3 years after treatment [32]. Several studies have used renal scintigraphy to evaluate renal status after SWL and have consistently found no significant effects [16, 31, 33, 34]. Other studies in pediatric patients have found no impact on serum creatinine or renal blood flow [35].

Taken together, these findings suggest that, despite the concerning results of animal studies, there seems to be few demonstrable effects of SWL on long-term function in pediatric kidneys. Nonetheless, it is likely prudent to minimize exposure of children to shock wave energy as much as possible. Strategies to reduce the number of shocks or the energy level of lithotripters during treatment have been successfully applied without an obvious decrease in efficacy.

One final safety consideration of specific concern in the pediatric population pertains to adjacent organ damage. The potential for lung injury has long been recognized, and experimental data in rats shows massive vascular and alveolar rupture and rapid death from a single SWL treatment directed at the chest [36]. Because in children the lungs are more proximate to the kidneys, special care needs to be taken to protect lung parenchyma from the shock waves, particularly for upper pole stones. The large F2 and high power of the original Dornier HM-3 were of particular concern, and most early SWL practitioners took care to shield the lung fields with shock wave-absorbing materials, such as sheets of polystyrene or foam. In practice, however, the most early series found low rates of acute lung injury. Occasional, but infrequent adverse events included hemoptysis [9, 16], and pulmonary edema [10]. As a rule, these patients recovered promptly, without longer term sequellae. The lower power settings (and smaller focal zone) of contemporary lithotripters means that problems with adjacent organ damage are less of a concern than previously, but pulmonary precautions such as shielding should still be taken particularly when treating small patients with upper pole stones.

Other treatment options do exist for children with urolithiasis. With progressive improvements in technology, endoscopic management of urolithiasis has become increasingly popular over the past 10–15 years, with ureteroscopy and laser lithotripsy supplanting SWL as the procedure of choice for many clinicians. A number of reports have compared outcomes in adult patients treated with SWL or ureteroscopy, and overall neither approach has emerged as clearly superior, particularly for proximal ureteral or renal stones. In general, stone-free rates and effectiveness are similar between URS and SWL [37–40], although retreatment rates are higher and SWL is less effective for large or obstructing stones [39]. Although serious complications are uncommon in both approaches, complication rates do tend to be higher with URS [37, 40] and patients more frequently need ancillary procedures (e.g., stent removal) [38].

Direct comparisons of endoscopic versus SWL in children have not been performed. Although the smaller patient size in the pediatric population magnifies the technical issues associated with endoscopic access to the upper tracts, several groups have reported good results in children [6, 41], and these procedures appear to have good safety profiles in properly selected pediatric patients. Whether potential long-term complications of endoscopic therapy (e.g., ureteral stricture) may outweigh potential renal injury after SWL remains to be determined.

In summary, SWL in children results in stone-free rates of 60–80% with contemporary equipment. Complication rates appear to be very low, although long-term risks remain uncertain. Despite advances in endoscopic equipment for endourologic management of stones, SWL continues to be an excellent option in children with stones.

References

1. Chaussy C, Brendel W, Schmiedt E (1980) Extracorporeally induced destruction of kidney stones by shock waves. Lancet 316:1265–1268
2. Chaussy C, Schmiedt E, Jocham D, Brendel W, Forssmann B, Walther V (1982) First clinical experience with extracorporeally induced destruction of kidney stones by shock waves. J Urol 127:417
3. Newman DM, Coury T, Lingeman JE, Mertz JH, Mosbaugh PG, Steele RE et al (1986) Extracorporeal shock wave lithotripsy experience in children. J Urol 136:238
4. Sigman M, Laudone VP, Jenkins AD, Howards SS, Riehle R Jr, Keating MA et al (1987) Initial experience with extracorporeal shock wave lithotripsy in children. J Urol 138:839
5. Jocham D, Chaussy C, Schmiedt E (1986) Extracorporeal shock wave lithotripsy. Urol Int 41:357
6. Kim SS, Kolon TF, Canter D, White M, Casale P (2008) Pediatric flexible ureteroscopic lithotripsy: the children's hospital of Philadelphia experience. J Urol 180:2616
7. Kurien A, Symons S, Manohar T, Desai M (2009) Extracorporeal shock wave lithotripsy in children: equivalent clearance rates to adults is achieved with fewer and lower energy shock waves. BJU Int 103:81
8. Frick J, Kohle R, Kunit G (1988) Experience with extracorporeal shock wave lithotripsy in children. Eur Urol 14:181
9. Kroovand RL, Harrison LH, McCullough DL (1987) Extracorporeal shock wave lithotripsy in childhood. J Urol 138:1106
10. Kramolowsky EV, Willoughby BL, Loening SA (1987) Extracorporeal shock wave lithotripsy in children. J Urol 137:939
11. Bohle A, Knipper A, Thomas S (1989) Extracorporeal shock wave lithotripsy in paediatric patients. Scand J Urol Nephrol 23:137
12. Nijman RJ, Ackaert K, Scholtmeijer RJ, Lock TW, Schroder FH (1989) Long-term results of extracorporeal shock wave lithotripsy in children. J Urol 142:609
13. Myers DA, Mobley TB, Jenkins JM, Grine WB, Jordan WR (1995) Pediatric low energy lithotripsy with the Lithostar. J Urol 153:453
14. Aksoy Y, Ozbey I, Atmaca AF, Polat O (2004) Extracorporeal shock wave lithotripsy in children: experience using a mpl-9000 lithotriptor. World J Urol 22:115
15. Defoor W, Dharamsi N, Smith P, Sekhon D, Colombo J, Riden D et al (2005) Use of mobile extracorporeal shock wave lithotripter: experience in a pediatric institution. Urology 65:778
16. Lottmann HB, Archambaud F, Traxer O, Mercier-Pageyral B, Helal B (2000) The efficacy and parenchymal consequences of extracorporeal shock wave lithotripsy in infants. BJU Int 85:311
17. Ramakrishnan PA, Medhat M, Al-Bulushi YH, Nair P, Al-Kindy A (2007) Extracorporeal shockwave lithotripsy in infants. Can J Urol 14:3684
18. Shukla AR, Hoover DL, Homsy YL, Perlman S, Schurman S, Reisman EM (2001) Urolithiasis in the low birth weight infant: the role and efficacy of extracorporeal shock wave lithotripsy. J Urol 165:2320
19. Nelson CP, Diamond DA, Cendron M, Peters CA, Cilento BG (2008) Extracorporeal shock wave lithotripsy in pediatric patients using a late generation portable lithotriptor: experience at Children's Hospital Boston. J Urol 180:1865
20. Tan AH, Al-Omar M, Watterson JD, Nott L, Denstedt JD, Razvi H (2004) Results of shockwave lithotripsy for pediatric urolithiasis. J Endourol 18:527
21. Shouman AM, Ziada AM, Ghoneim IA, Morsi HA (2009) Extracorporeal shock wave lithotripsy monotherapy for renal stones >25 mm in children. Urology 74:109
22. Orsola A, Diaz I, Caffaratti J, Izquierdo F, Alberola J, Garat JM (1999) Staghorn calculi in children: treatment with monotherapy extracorporeal shock wave lithotripsy. J Urol 162:1229
23. Al-Busaidy SS, Prem AR, Medhat M (2003) Pediatric staghorn calculi: the role of extracorporeal shock wave lithotripsy monotherapy with special reference to ureteral stenting. J Urol 169:629
24. D'Addessi A, Bongiovanni L, Racioppi M, Sacco E, Bassi P (2008) Is extracorporeal shock wave lithotripsy in pediatrics a safe procedure? J Pediatr Surg 43:591
25. Krambeck AE, Gettman MT, Rohlinger AL, Lohse CM, Patterson DE, Segura JW (2006) Diabetes mellitus and hypertension associated with shock wave lithotripsy of renal and proximal ureteral stones at 19 years of follow up. J Urol 175:1742
26. Sato Y, Tanda H, Kato S, Ohnishi S, Nakajima H, Nanbu A et al (2008) Shock wave lithotripsy for renal stones is not associated with hypertension and diabetes mellitus. Urology 71:586
27. Neal DE Jr, Kaack MB, Harmon EP, Puyau F, Morvant A, Richardson E et al (1991) Renin production after experimental extracorporeal shock wave lithotripsy: a primate model. J Urol 146:548
28. Claro JA, Denardi F, Ferreira U, Rodrigues NN Jr, Saldanha LB, Figueiredo JF (1994) Effects of extracorporeal shockwave lithotripsy on renal growth and function: an animal model. J Endourol 8:191
29. Lifshitz DA, Lingeman JE, Zafar FS, Hollensbe DW, Nyhuis AW, Evan AP (1998) Alterations in predicted growth rates of pediatric kidneys treated with extracorporeal shockwave lithotripsy. J Endourol 12:469
30. Villanyi KK, Szekely JG, Farkas LM, Javor E, Pusztai C (2001) Short-term changes in renal function after extracorporeal shock wave lithotripsy in children. J Urol 166:222
31. Wadhwa P, Aron M, Bal CS, Dhanpatty B, Gupta NP (2007) Critical prospective appraisal of renal morphology and function in

children undergoing shockwave lithotripsy and percutaneous nephrolithotomy. J Endourol 21:961
32. Goel MC, Baserge NS, Babu RV, Sinha S, Kapoor R (1996) Pediatric kidney: functional outcome after extracorporeal shock wave lithotripsy. J Urol 155:2044
33. Picramenos D, Deliveliotis C, Alexopoulou K, Makrichoritis C, Kostakopoulos A, Dimopoulos C (1996) Extracorporeal shock wave lithotripsy for renal stones in children. Urol Int 56:86
34. Traxer O, Lottmann H, Archambaud F, Helal B, Mercier-Pageyral B (1999) Extracorporeal lithotripsy in children. Study of its efficacy and evaluation of renal parenchymal damage by DMSA-Tc 99 m scintigraphy: a series of 39 children. Arch Pediatr 6:251
35. Thomas R, Frentz JM, Harmon E, Frentz GD (1992) Effect of extracorporeal shock wave lithotripsy on renal function and body height in pediatric patients. J Urol 148:1064
36. Pode D, Landau EL, Lijovetzky G, Shapiro A (1989) Isolated pulmonary blast injury in rats–a new model using the extracorporeal shock-wave lithotriptor. Mil Med 154:288
37. Youssef RF, El-Nahas AR, El-Assmy AM, El-Tabey NA, El-Hefnawy AS, Eraky I et al (2009) Shock wave lithotripsy versus semirigid ureteroscopy for proximal ureteral calculi (<20 mm): a comparative matched-pair study. Urology 73:1184
38. Stewart GD, Bariol SV, Moussa SA, Smith G, Tolley DA (2007) Matched pair analysis of ureteroscopy versus shock wave lithotripsy for the treatment of upper ureteric calculi. Int J Clin Pract 61:784
39. Lee YH, Tsai JY, Jiaan BP, Wu T, Yu CC (2006) Prospective randomized trial comparing shock wave lithotripsy and ureteroscopic lithotripsy for management of large upper third ureteral stones. Urology 67:480
40. Pearle MS, Lingeman JE, Leveillee R, Kuo R, Preminger GM, Nadler RB et al (2008) Prospective randomized trial comparing shock wave lithotripsy and ureteroscopy for lower pole caliceal calculi 1 cm or less. J Urol 179:S69
41. Smaldone MC, Cannon GM Jr, Wu HY, Bassett J, Polsky EG, Bellinger MF et al (2007) Is ureteroscopy first line treatment for pediatric stone disease? J Urol 178:2128