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SLOW VERSUS FAST SHOCK WAVE LITHOTRIPSY RATE FOR UROLITHIASIS: A PROSPECTIVE RANDOMIZED STUDY

KHALED MADBOULY, ABDEL MONEIM EL-TIRAIFI, MOHAMED SEIDA, SALAH R. EL-FAQIH, RAMIZ ATASSI AND RIYADH F. TALIC*

From the Division of Urology, Department of Surgery, College of Medicine, King Khalid University Hospital, King Saud University, Riyadh, Kingdom of Saudi Arabia

ABSTRACT

Purpose: We determined the effect of shock wave lithotripsy (SWL) rate on treatment outcome in patients with renal and ureteral stones.

Materials and Methods: A total of 156 patients were prospectively randomized to receive SWL using a slow (60 pulses per minute) or fast wave rate (120 pulses per minute). Inclusion criteria were patients with a single radiopaque renal or ureteral stone not exceeding 30 mm in maximum diameter. Patient characteristics, stone and therapy features were reviewed, and the relation to success rate and total number of shock waves required was assessed using the chi-square, Fisher exact and Mann-Whitney tests. Factors proven to be significant in univariate analysis were entered in a multivariate logistic regression analysis.

Results: The study included 114 male (73.1%) and 42 female (26.9%) patients with a mean age ± SD of 42.1 ± 13.3 years. Stone length measured in maximum diameter was 13.2 ± 5.9 mm (range 5 to 30). Renal stones were encountered in 94 (60.3%) patients and ureteral stones in 62 (39.7%). The slow SWL rate was used in 76 (48.7%) patients and the fast rate in 80 (51.3%). Baseline variables were comparable in both groups. However, the total number of shock waves required was statistically significantly lower in the slow rate group ($p = 0.004$) and the treatment time was significantly longer ($p = 0.000$). The rate of success, defined as being completely stone-free or having clinically insignificant gravel less than 2 mm, was significantly higher with the slow rate ($p = 0.034$), an increased number of sessions ($p = 0.001$), decreased stone length ($p = 0.000$) and greater total number of shock waves ($p = 0.011$). However, only the slow SWL rate and stone length maintained a statistically significant impact in multivariate analysis.

Conclusions: The slow SWL rate is associated with a significantly higher success rate at a lower number of total shock waves compared to the fast SWL rate.

KEY WORDS: lithotripsy, urinary calculi, ultrasonics, treatment outcome

Treatment of patients with urinary calculi has undergone a dramatic change since the introduction of extracorporeal shock wave lithotripsy that proved to be highly effective with little morbidity.[1] Newer lithotriptors with the ungated shock wave technique (nonelectrocardiogram synchronized shock wave generation) allowed more rapid treatments. Currently administration of shock wave lithotripsy (SWL) at rates of 100 to 120 shock waves (sws)/per minute is commonplace in contrast to rates of 60 to 80 shock waves per minute in the original Dornier HM3 (Dornier Medical Systems, Munich, Germany).[2]

The effect of shock wave (SW) rate on stone comminution has been assessed by many authors using a variety of in vitro and animal models. It has been demonstrated that decreasing the SW rate may improve stone fragmentation.[3–5] However, in vitro experiments may not have adequate reproduction of the environment of a stone within the kidney nor the state of shock wave transmission through the body. Our study tested the hypothesis that changing the SW rate alters the success rate after SWL in the clinical setting.

PATIENTS AND METHODS

Between June 2001 and February 2002, 156 patients were prospectively randomized to receive SWL using either a slow SW (60 pulses per minute) or fast rate (120 pulses per minute) using an electromagnetic Siemens Lithostar Multiline lithotriptor (Siemens AG, Munich, Germany). Inclusion criteria were patients with a single, radiopaque renal or ureteral stone not greater than 30 mm in maximum diameter.

A complete pretreatment evaluation and excretory urography were performed in all patients. Stone length was measured as the maximal stone diameter. Any patient with bleeding disorders, obstruction distal to the stone or severe uncontrolled urinary tract infection was excluded from study. Informed consent was obtained from all patients before treatment.

All patients were treated while under epidural, spinal or general anesthesia. Patients with renal or upper ureteral calculi were treated in the supine position. For lower ureteral stones patients were turned prone. Patients were discharged home the next day after a plain radiograph was obtained. All treatments were supervised by 2 urologists (KM and MS).

Followup data were collected and analyzed at the 3-month visit. Success was defined as being completely stone-free or having clinically insignificant gravel smaller than 2 mm. Patient characteristics, stone and therapy features were reviewed and correlated to success and SWL rates using the chi-square, Fisher exact and Mann-Whitney tests with differences considered statistically significant if $p < 0.05$ (table 1). Factors proven to be significant in univariate analysis

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* Correspondence: Department of Surgery (37), P.O. Box 7805, Riyadh 11472, King Khalid University Hospital, Kingdom of Saudi Arabia (telephone: 96614671836; cellular: 966505440016; FAX: 96614679493; e-mail: rftalic@hotmail.com).

TABLE 1. *Patient, stone, renal and therapy characteristics*

Characteristic	Total	Slow Rate Group	Fast Rate Group	p Value	Test
No. pts (%)	156 (100)	76 (48.7)	80 (51.3)	—	—
Mean age ± SD	42.1 ± 13.3	42.0 ± 14.5	42.2 ± 12.2	0.876	Mann-Whitney
No. sex (%):					
Male	114 (73.1)	58 (76.3)	56 (70.0)	0.374	Chi-square
Female	42 (26.9)	18 (23.7)	24 (30.0)		
Mean mm stone length ± SD	13.2 ± 5.9	13.2 ± 5.8	13.2 ± 6.0	0.888	Mann-Whitney
No. mm stone length (%):					
15 or Less	111 (71.2)	55 (72.4)	56 (70.0)	0.744	Chi-square
Greater than 15	45 (28.8)	21 (27.6)	24 (30.0)		
No. side (%):					
Rt	80 (51.3)	40 (52.6)	40 (50.0)	0.742	Chi-square
Lt	76 (48.7)	36 (47.4)	40 (50.0)		
No. nature (%):					
New onset	123 (78.8)	61 (80.3)	62 (77.5)	0.673	Chi-square
Recurrent	33 (21.2)	15 (19.7)	18 (22.5)		
No. site (%):					
Renal	94 (60.3)	46 (60.5)	48 (60.0)	0.946	Chi-square
Ureteral	62 (39.7)	30 (39.5)	32 (40.0)		
No. renal radiology (%):					
Perfect	89 (57.1)	41 (53.9)	48 (60.0)	0.544	Chi-square
Mild hydronephrosis	39 (25.0)	20 (26.4)	19 (23.8)		
Moderate hydronephrosis	24 (15.3)	14 (18.4)	10 (12.5)		
Severe hydronephrosis	4 (2.6)	1 (1.3)	3 (3.7)		
No. procedures before SWL (%):					
None	121 (77.6)	56 (73.7)	65 (81.2)	0.258	Chi-square
Double-J stent	35 (22.4)	20 (26.3)	15 (18.8)		
No. anesthesia (%):					
General	107 (68.6)	62 (81.6)	45 (56.3)	0.001	Chi-square
Spinal/epidural	49 (31.4)	14 (18.4)	35 (43.7)		
No. pt position (%):					
Supine	124 (79.5)	62 (81.6)	62 (77.5)	0.528	Chi-square
Prone	32 (20.5)	14 (18.4)	18 (22.5)		
No. sessions (%):					
1	121 (77.6)	61 (80.3)	60 (75.0)	0.636	Chi-square
2	25 (16.0)	10 (13.1)	15 (18.8)		
3	10 (6.4)	5 (6.6)	5 (6.2)		
Mean total shots ± SD	6,606 ± 4,052	5,755 ± 3,348	7,414 ± 4,495	0.004	Mann-Whitney
Mean intensity ± SD	7.1 ± 1.7	7.4 ± 1.6	6.8 ± 1.8	0.071	Mann-Whitney
Mean treatment time ± SD	78.4 ± 50.1	95.9 ± 55.8	61.7 ± 37.5	0.000	Mann-Whitney

were included in a logistic regression model (stepwise regression with backward elimination using likelihood ratio)[6] to identify the factors that independently affected the success rate.

RESULTS

The study included 114 male (73.1%) and 42 female patients (26.9%) with a mean age (±SD) of 42.1 (±13.3) years (range 5 to 75). All stones were single and radiopaque including 94 in the kidney, 62 in the ureter, 80 on the right side, 76 on the left, 123 new onset and 33 recurrent. Of the renal units 82% were normal or showing mild hydronephrosis. Mean (SD) stone length was 13.2 (5.9) mm (range 5 to 30).

Baseline variables including patient, stone and renal characteristics were comparable in both groups. However, the total number of shock waves required was statistically significantly lower in the slow rate group ($p = 0.004$). However, treatment time was significantly shorter in the fast rate group ($p = 0.000$, table 1).

The success rate was 94.2% in the whole patient population. It was 98.7% (75 of 76) in the slow rate group versus 90% (72 of 80) in the fast rate group ($p = 0.034$). Stone-free state was achieved in 133 (85.2%) patients. Four factors had a statistically significant impact on the success rate including SWL rate ($p = 0.034$), number of sessions ($p = 0.001$), stone length ($p = 0.000$) and total number of shock waves required ($p = 0.011$, table 2). However, only the SWL rate and stone length maintained their statistically significant impact in multivariate analysis (table 3).

DISCUSSION

Shock wave lithotripsy has been shown to be performed safely in an electrocardiogram gated or externally fixed rate signal generator (nongated) fashion. The effect of SW rate on stone comminution has been assessed by many authors using a variety of in vitro models. Wiksell and Kinn, using an electrohydraulic lithotriptor and ceramic spheres, reported that a SW interval of 0.4 seconds produced a few large fragments, whereas a 2-second interval shattered the spheres into many small fragments.[7] Greenstein and Matzkin used an Econolith 2000 lithotriptor (Medispec, Germantown, Maryland) on 118 ceramic stones at rates of 30, 60, 120 and 150 shock waves per minute at 3 energy levels (15, 20 and 22 kV).[3] The authors reported improved stone fragmentation at the higher energy levels (20 and 22.5 kV) and at lower rates (30 and 60 shock waves per minute) of SW delivery. Weir et al fragmented 12 mm standardized solid spherical blaster stones using a Dornier MFL 5000 lithotriptor at an energy setting of 20 kV.[4] More shocks were required for stone fragmentation at 117 shocks/per minute compared to 60 and 80 shock waves per minute.

Human kidney stones have also been used during in vitro studies of SW rate. Vallancien et al subjected single human kidney stones to a series of 3,000 shock waves at variable frequencies of 1.25, 2.5, 5 and 10 shock waves per second using the EDAP LT.01 piezoelectric lithotriptor (EDAP TMS, Lyon, France).[8] Better fragmentation of hard stones was achieved using slower frequencies of 1.25 and 2.5 shock waves per second at the cost of a longer mean treatment time. More recently Paterson et al assessed the effect of SW rate on stone comminution in vivo using artificial stones implanted into pig kidneys via upper pole percutaneous access.[5] They used SW rates of 30 and 120 shock waves per minute. Results showed that stone comminution is significantly improved by decreasing the rate of shock wave delivery.

Our stone-free rate (85.2%) compares favorably with that

TABLE 2. *Univariate analysis of the impact of different patient, stone, renal and therapy factors on success rate*

Variable	Success	Failure	p Value	Test
Mean age ± SD	42.1 ± 13.2	41.4 ± 15	0.744	Mann-Whitney
No. sex (%):				
Male	108 (94.7)	6 (6.3)	0.703	Fisher's exact
Female	39 (92.9)	3 (7.1)		
Mean mm stone length ± SD	12.8 ± 5.7	20.2 ± 4.3	0.000	Mann-Whitney
No. mm stone length (%):				
15 or Less	110 (99.1)	1 (0.9)	0.000	Fisher's exact
Greater than 15	37 (82.2)	8 (17.8)		
No. side (%):				
Rt	75 (93.7)	5 (6.3)	1.000	Fisher's exact
Lt	72 (94.7)	4 (5.3)		
No. nature (%):				
New onset	118 (95.9)	5 (4.1)	0.095	Fisher's exact
Recurrent	29 (87.9)	4 (12.1)		
No. site (%):				
Renal	86 (91.5)	8 (8.5)	0.088	Fisher's exact
Ureteral	61 (98.4)	1 (1.6)		
No. renal radiology (%):				
Normal	84 (94.4)	5 (5.6)	0.890	Chi-square
Mild hydronephrosis	36 (92.3)	3 (7.7)		
Moderate hydronephrosis	23 (95.8)	1 (4.2)		
Severe hydronephrosis	4 (100.0)	—		
No. procedures before SWL (%):				
None	115 (95.0)	6 (5.0)	0.421	Fisher's exact
Double-J stents	32 (91.4)	3 (8.6)		
No. anesthesia (%):				
General	102 (95.3)	5 (4.7)	0.463	Fisher's exact
Spinal/epidural	45 (91.8)	4 (8.2)		
No. pt position (%):				
Supine	115 (92.7)	9 (7.3)	0.205	Fisher's exact
Prone	32 (100.0)	—		
No. SWL rate (%):				
Slow	75 (98.7)	1 (1.3)	0.034	Fisher's exact
Fast	72 (90.0)	8 (10.0)		
No. sessions (%):				
1	118 (97.5%)	3 (2.5)	0.001	Chi-square
2	22 (88.0)	3 (12.0)		
3	7 (70.0)	3 (30.0)		
Mean total shots ± SD	6,323 ± 3,734	11,230 ± 6,068	0.011	Mann-Whitney
Mean intensity ± SD	7.2 ± 1.8	6.4 ± 1.2	0.260	Mann-Whitney

TABLE 3. *Logistic regression analysis of the variables having impact on the success rate*

Variable	Regression Coefficient (B)	Odds of Success*	p Value
ESWL rate:			
Slow	2.234	9.333	0.043
Fast	0	1	
Stone length (mm):			
15 or Less	3.241	25.571	0.003
Greater than 15	0	1	
Constant	0.868	2.382	0.050

* Compared to reference category.

of other reports.[1,9] The study proves clinically that a slow SWL rate is associated with a significantly higher success rate (p = 0.034) at a lower number of required total shock waves (p = 0.004). Total treatment time was significantly longer in the slow rate group (p = 0.000). Although the rate was reduced by 1 half, treatment time did not double due to the decreased number of shock waves required for successful stone fragmentation. Furthermore, we expect that the longer treatment time will be compensated by decreased retreatment sessions resulting from the improved success rate, albeit not demonstrated statistically in our study most probably because of the small number of patients.

The exact mechanism responsible for a rate effect on the efficiency of SWL is still unknown. In SWL 2 basic mechanisms of stone fragmentation have been well documented, namely spalling at the posterior surface and at internal crystalline-matrix interfaces of a stone due to reflected tensile waves and cavitation erosion at the anterior surface of a stone due to violent collapse of bubbles.[10–12] It has been suggested that an increased shock wave rate results in amplification of cavitation activity at the focus of a lithotriptor.[4,13,14] At fast rates of SWL bubbles generated by the incident SW may not have time to dissipate and, thus, combine with each other to form a bubble cloud. The persistent bubble cloud interferes with the transmission of incoming shock waves.[7]

Although SWL is minimally invasive, it is not without acute complications and potential long-term risks of hypertension and renal insufficiency.[15,16] Animal and cell suspension studies have shown that decreasing the SW rate may reduce the level of such tissue injury. Delius et al studied the effect of SW rate on canine kidneys treated with 3,000 sws at 20 kV using the Dornier HM3 lithotriptor.[17] The SW rates used were 100 sws and 1 shock wave per second. The animals were sacrificed 24 hours after lithotripsy and the fast rate was associated with a significantly greater renal parenchymal hemorrhage. Ryan et al compared the effect of 6,000 piezoelectric shock waves on rabbits using 2.5 and 20 shock waves per second lithotripsy rates.[18] The fast SWL rate was associated with significantly greater acute histological damage 24 hours after lithotripsy.

Human studies have also shown a decrease in the incidence of SWL induced renal injury and need for sedation or anesthesia when slower rates of SWL are used. Vallancien et al reported a reduction from 2.5% to 0.2% in the incidence of subcapsular hematomas when a slower rate of SWL was used.[8] Robert et al reported a statistically lower incidence of intravenous sedation and analgesia use for upper ureteral stones treated at the frequency of 1 rather than 4 shock waves per second using an EDAP LT.02 piezoelectric lithotriptor.[19] Furthermore, SWL associated renal injury and deterioration of renal function were shown to be dose dependent and to increase proportionally with more treatment shocks.[20] Our study proves that a greater number of shock waves were required in the fast rate group with more tendency for renal injury.

CONCLUSIONS

Shockwave lithotripsy rate has an independent significant impact on the success rate after SWL. Decreasing the rate of shock wave administration increases the success rate of SWL at a smaller number of shock waves. We recommend the use of the slow SWL rate in the clinical setting based on the improved success rate and the assumed reduction in renal injury.

REFERENCES

1. Drach, G. W., Dretler, S., Fair, W., Finlayson, B., Gillenwater, J., Griffith, D., Lingeman, J. et al: Report of the United States Cooperative Study of Extracorporeal Shock Wave lithotripsy. J Urol, **135:** 1127, 1986
2. Paterson, R. F., Kuo, R. L. and Lingeman, J. E.: The effect of rate of shock wave delivery on the efficiency of lithotripsy. Curr Opin Urol, **12:** 291, 2002
3. Greenstein, A. and Matzkin, H.: Does the rate of extracorporeal shock wave delivery affect stone fragmentation? Urology, **54:** 430, 1999
4. Weir, M. J., Tariq, N. and Honey, R. J.: Shockwave frequency affects fragmentation in a kidney stone model. J Endourol, **14:** 547, 2000
5. Paterson, R. F., Lifshitz, D. A., Lingeman, J. E., Evan, A. P., Connors, B. A., Fineberg, N. S. et al: Stone fragmentation during shock wave lithotripsy is improved by slowing the shock wave rate: studies with a new animal model. J Urol, **168:** 2211, 2002
6. Norusis, M. J. and SPSS, Inc.: Logistic regression analysis. In: SPSS 6.1 Advanced Statistics User Guide. Chicago: SPSS Inc., chapt. 1, pp. 1–56, 1994
7. Wiksell, H. and Kinn, A. C.: Implications of cavitation phenomena for shot intervals in extracorporeal shock wave lithotripsy. Br J Urol, **75:** 720, 1995
8. Vallancien, G., Munoz, R., Borghi, M., Veillon, B., Brisset, J. M. and Daudon, M.: Relationship between the frequency of piezoelectric shock waves and the quality of renal stone fragmentation. In vitro study and clinical implications. Eur Urol, **16:** 41, 1989
9. Lingeman, J. E., Newman, D., Mertz, J. H. O., Mosbaugh, P. G., Steele, R. E., Kahnoski, R. J. et al: Extracorporeal shock wave lithotripsy: the Methodist Hospital of Indiana experience. J Urol, **135:** 1134, 1986
10. Lokhandwalla, M. and Sturtevant, B.: Fracture mechanics model of stone comminution in ESWL and implications for tissue damage. Phys Med Biol, **45:** 1923, 2000
11. Sass, W., Braunlich, W. M., Dreyer, H. P., Matura, E., Folberth, W., Preismeyer, H. G. et al: The mechanisms of stone disintegration by shock waves. Ultrasound Med Biol, **7:** 239, 1991
12. Zhong, P., Chuong, C. J. and Preminger, G. M.: Propagation of shock waves in elastic solids caused by cavitation microjet impact. II: Application in extracorporeal shock wave lithotripsy. J Acoust Soc Am, **94:** 29, 1993
13. Huber, P., Jochle, K. and Debus, J.: Influence of shock wave pressure amplitude and pulse repetition frequency on the lifespan, size and number of transient cavities in the field of an electromagnetic lithotriptor. Phys Med Biol, **43:** 3113, 1998
14. Zeman, R. K., Davros, W. J., Garra, B. S. and Horii, S. C.: Cavitation effects during lithotripsy. Part I. Results of in vitro experiments. Radiology, **177:** 157, 1990
15. Janetscheck, G., Frauscher, F., Knapp, R., Hofle, G., Peschel, R. and Bartsch, G.: New onset hypertension after extracorporeal shock wave lithotripsy: age related incidence and prediction by intrarenal resistive index. J Urol, **158:** 346, 1997
16. Evan, A. P., Willis, L. R., Lingeman, J. E. and McAteer, J. A.: Renal trauma and the risk of long-term complications in shock wave lithotripsy. Nephron, **78:** 1, 1998
17. Delius, M., Jordan, M., Eizenhoefer, H., Marlinghaus, E., Heine, G., Liebich, H. G. et al: Biological effects of shock waves: kidney haemorrhage by shock waves in dogs—administration rate dependence. Ultrasound Med Biol, **14:** 689, 1988
18. Ryan, P. C., Jones, B. J., Kay, E. W., Nowlan, P., Kiely, E. A., Gaffney, E. F. et al: Acute and chronic bioeffects of single and multiple doses of piezoelectric shockwaves (EDAP LT.01). J Urol, **145:** 399, 1991
19. Robert, M., Rakotomalala, E., Delbos, O. and Navartil, H.: Piezoelectric lithotripsy of ureteral stones: influence of shockwave frequency on sedation and therapeutic efficiency. J Endourol, **13:** 157, 1999
20. Willis, L. R., Evan, A. P. and Lingeman, J. E.: The impact of high-dose lithotripsy on renal function. Contemp Urol, **11:** 45, 1999