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ORIGINAL ARTICLE

Comparison of electrohydraulic and electromagnetic extracorporeal shock wave lithotriptors for upper urinary tract stones in a single center

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Abstract

Purpose To compare the efficacy and outcomes of shock wave lithotripsy (SWL) for upper urinary tract stones with an electrohydraulic (EH) and an electromagnetic (EM) lithotriptor in a single center.

Methods The medical records of 272 patients with upper urinary tract stones ≤ 2 cm in size who underwent SWL with either the Medispec E3000 EH lithotriptor (179 cases) or the Medispec EM1000 EM lithotriptor (93 cases) were reviewed. The demographic data, stone parameters, stone-free rates, and retreatment rates were analyzed.

Results The EH group had a higher stone-free rate (53.6 vs. 30.1%, $p < 0.001$) and a lower retreatment rate (32.4 vs. 61.2%, $p < 0.001$) for renal and upper third ureteral stones than the EM group. The stone-free rates for renal stones < 1 cm (55.5 vs. 32.2%, $p = 0.045$), ureteral stones < 1 cm (64.5 vs. 42.1%, $p = 0.028$), and renal stones ≥ 1 cm (43.1 vs. 0%, $p = 0.03$) were higher in the EH group. Two patients in the EH group had a renal hematoma needing hospitalization after SWL. There were no complications in the EM group.

Conclusions The Medispec E3000 EH lithotriptor had higher stone-free rates and lower retreatment rates than the Medispec EM1000 EM lithotriptor for renal stones < 2 cm and ureteral stones < 1 cm. Complications were rare.

Keywords Kidney · Ureter · Stone · Shock wave lithotripsy

Introduction

Extracorporeal shock wave lithotripsy (SWL) has been applied clinically for over 30 years [1]. In addition to the electrohydraulic (EH) energy source used in the original lithotriptor, other energy sources such as piezoelectric and electromagnetic (EM) have been gradually introduced. Previous studies compared the efficacy and safety of different energy shock wave machines, but there are few comparative studies between EH and EM SWL in a single center [2]. The main advantage of EM SWL is that it requires no anesthesia, but some authors reported a lower stone-free rate compared to EH SWL, which has a higher energy level and a higher complication rate [3, 4]. However, most recent studies reported similar outcomes and complication rates with these two kinds of lithotriptors. An EH lithotriptor (E3000, Medispec, Israel) and an EM lithotriptor (EM1000, Medispec, Israel) were simultaneously installed at two branches of our medical center. The same two experienced technicians operated both lithotriptors under the supervision of the same urologists. In this study, we compared the efficacies and outcomes of these two machines in the treatment of upper urinary tract stones.

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Patients and methods

We retrospectively reviewed the medical records of patients undergoing SWL at both hospital branches between January 2011 and June 2013. In this period, 272 patients with a solitary radio-opaque upper urinary tract stone between 5 mm and 2 cm in size underwent SWL. Patients with multiple renal or ureteral stones, congenital anomalies, urinary diversion, urosepsis, and coagulopathy were excluded. Patients undergoing combination therapy with other treatment modalities and pediatric patients were also excluded.

Plain radiography of kidney, ureter, and bladder (KUB), renal ultrasonography, intravenous urography, abdominal computed tomography (CT), or a combination of these were used for diagnosis before SWL. The stones were categorized by location into renal, upper, middle, or lower ureteral stones. Because all patients had a KUB taken preoperatively, stone size was measured on a KUB in one dimension. All SWL treatments were performed in an outpatient basis by the same operators for both machines. Patients were evaluated within 4 weeks after lithotripsy by KUB and renal ultrasonography. Because some of the patients undergoing SWL had obstructive hydronephrosis preoperatively, renal ultrasonography was performed post-operatively to determine whether hydronephrosis persisted due to incomplete stone fragmentation or if hydronephrosis subsided after complete stone disintegration and restored ureteral patency. Hydronephrosis would also be seen in patients with renal stones fragments passing into the ureter post-operatively. Renal ultrasonography served as a tool in the evaluation of SWL efficacy; however, the post-operative stone-free status was based on KUB. In this study, we measured the stone sizes immediately pre- and post-SWL, and searched the medical records for any complications and retreatment modalities.

During SWL, the energy level was gradually increased from 14 to 22 kV in the EH lithotriptor and to 24 kV in the EM lithotriptor. Shock wave rate was set at 120 shocks per minute. The maximum number of shock waves delivered in a session was 3500 for the EH lithotriptor and 4000 for the EM lithotriptor, depending on fragmentation status and patient tolerance. Patients in the EH group were placed under intravenous sedation with one ample of propofol and dormicum, while those in the EM group received no anesthesia. Stone-free status was defined as the absence of stone on imaging, while retreatment was defined as the presence of residual stone fragments > 5 mm requiring further surgical management. Retreatment in the form of repeat SWL, percutaneous nephrolithotomy, rigid ureteroscopic lithotripsy, or retrograde intrarenal surgery RIRS was performed depending on stone location and surgeon preference. *T* test and Chi-square test were used for statistical analysis, and statistical significance was set at $p < 0.05$.

Table 1 Stone location

Location	Electrohydraulic *n*(%)	Electromagnetic *n* (%)	*p* value
Kidney	89 (49.7%)	45 (48.3%)	0.835
Ureter	90 (50.2%)	48 (51.6%)	0.835
Upper	54 (30.1%)	30 (32.2%)	
Middle	18 (10.05%)	9 (9.67%)	
Lower	18 (10.05%)	9 (9.67%)	

Table 2 Stone-free rates by stone location and size

	Electrohydraulic *n* (%)	Electromagnetic *n* (%)	*p* value
Overall	96/179 (53.6%)	28/93 (30.1%)	<0.001
Kidney	44/89 (49.4%)	10/45 (22.2%)	0.002
Upper ureter	33/54 (61.1%)	10/30 (33.3%)	0.015
Middle ureter	10/18 (55.5%)	3/9 (33.3%)	0.276
Lower ureter	9/18 (50.0%)	5/9 (55.5%)	0.785
Stone size < 1 cm			
Kidney	25/45 (55.5%)	10/31 (32.2%)	0.045
Ureter	40/62 (64.5%)	16/38 (42.1%)	0.028
Stone size ≥ 1 cm			
Kidney	19/44 (43.1%)	0/14 (0%)	0.003
Ureter	12/28 (42.8%)	2/10 (20.0%)	0.198

Results

A total of 272 patients were treated, including 179 by EH and 93 by EM SWL. The mean age was 50.1 ± 11.47 years in the EH group and 51.4 ± 12.01 years in the EM group. The mean stone size was 0.9 ± 0.31 cm in the EH group and 0.8 ± 0.29 cm in the EM group. There were no significant differences in patient characteristics between the two groups in terms of patient sex ($p = 0.06$), age ($p = 0.37$), and stone size ($p = 0.11$). However, more patients in the EH group (75/179, 41.8%) had pre-SWL hydronephrosis than in the EM group (26/93, 27.9%), while more patients in the EM group (18/93, 19.3%) received pre-SWL DJ stent placement than in the EH group (19/179, 10.6%) (all $p < 0.05$). There were no significant differences in stone location and stone size between the two groups (Table 1).

The treatment results were stratified by stone location (kidney, upper ureter, middle ureter, and lower ureter) and stone size (< 1 and ≥ 1 cm). The EH group had a higher overall stone-free rate than the EM group (53.6 vs. 30.1%, $p < 0.001$) (Table 2). The EH group had a lower overall retreatment rate than the EM group (32.4 vs. 61.2%, $p < 0.001$) (Table 3).

The stone-free rates and retreatment rates for kidney stones, upper ureter stones and ureter stones less than 1 cm

Table 3 Retreatment rates by stone location and size

	Electrohydraulic *n* (%)	Electromagnetic *n* (%)	*p* value
Overall	58/179 (32.4%)	57/93 (61.2%)	<0.001
Kidney	28/89 (31.4%)	29/45 (64.4%)	<0.001
Upper ureter	15/54 (27.7%)	19/30 (63.3%)	0.01
Middle ureter	6/18 (33.3%)	5/9 (55.5%)	0.268
Lower ureter	9/18 (50.0%)	4/9 (44.4%)	0.785
Stone size < 1 cm			
Kidney	11/45 (24.4%)	18/31 (58.0%)	0.003
Ureter	16/62 (25.8%)	21/38 (55.2%)	0.003
Stone size ≥ 1 cm			
Kidney	17/44 (35.6%)	11/14 (78.5%)	0.009
Ureter	14/28 (50.0%)	7/10 (70.0%)	0.275

in size were significantly better in the EH group than in the EM group ($p < 0.05$). However, there were no statistically significant differences in stone-free and retreatment rates between the two groups for stones in the middle and lower ureter and for ureteral stones 1 cm or larger in size ($p > 0.05$).

Two patients in the EH group had a renal hematoma post-SWL. These two patients suffered from severe right flank pain refractory to analgesics at the recovery room. Emergent bedside ultrasonography suspected and CT confirmed the diagnosis of renal hematoma. Both patients were hospitalized and one received a blood transfusion. There were no complications in the EM group.

Discussion

Upper urinary tract calculi can be treated with shock wave machines with different energy sources. While acceptable success rates have been reported using different lithotripters, only a few studies have compared the efficacy of EH and EM lithotripters. It is difficult to compare the efficacy of different lithotriptors between institutions due to variabilities in patient selection, treatment protocols, definition of treatment success, fluoroscopic image quality, follow-up protocols, and reported retreatment modalities. In addition, judgement may vary among different operators when determining the number of shock waves that need to be administered in each session. The present study compared the efficacy and safety of an EH and an EM lithotriptor in a single center by the same group of urologists with set surgical indications and follow-up criteria.

Many factors may influence SWL efficacy, including stone size and location, body mass index, skin-to-stone distance, fluoroscopic image quality, frequency of shock waves, and number of shock waves administered. Operator experience and treatment strategy may therefore affect SWL efficacy. In this study, the patient and stone characteristics were similar in the EH and EM groups. The strength of this study was that the same two experienced technicians operated both machines and performed all the procedures, which minimized operator-related bias.

Previous studies reported that the stone-free rate of EH lithotriptors ranged from 47 to 92% [5, 6]. A few studies compared EH and EM lithotriptors with variable results. Teichman et al. studied the efficacy of various SWL machines for human calculi in vitro [7]. Results showed that the Dornier HM-3 (EH), Storz Modulith SLX (EM) and Siemens Lithostar C (EM) had comparable fragmentation efficacies, and were superior to the Dornier Doli (EM), Medstone STS-T (EH), HealthTronics LithoTron 160 (EH), and Medispec Econolith (EH) lithotriptors. Schmid et al. demonstrated a higher stone-free rate with the Dornier HM3 (EH) lithotriptor than with the Siemens Lithostar Plus (EM) lithotriptor (89 vs. 64%, $p = 0.004$) in the treatment of solitary kidney stones [4]. Matin et al. reported a higher stone-free rate but also a higher rate of total adjunctive measures with the Dornier MFL 5000 (EH) than with the Storz Modulith SLX (EM) lithotriptor [3]. However, the efficiency quotients were equivalent, implying that these lithotripsy units were equally efficacious.

Jamshaid et al. and Alanee et al. reported that EH and EM lithotriptors (Dornier MPL 9000 vs. Siemens Modulars and Medstone STS-T vs. Storz Modulith SLX, respectively) were equally efficacious in the treatment of different stone sizes and most stone sites and had similar safety profiles [2, 8]. In contrast, Tailly et al. compared four Dornier lithotriptors (two EH and two EM) and found a slight increase in efficacy and slight decrease in retreatment rates in the newer EM lithotriptors when compared to the older EH units [9]. Sheir et al. also compared two Dornier lithotriptors, the MFL 5000 (EH) and DLS (EM), and showed significantly higher success rate, lower treatment time, and lower retreatment rate with the EM lithotriptor in the treatment of renal stones [10]. However, this Dornier MFL 5000 was also reported by Fialkov et al. to be less effective than comparable EH and

EM lithotriptors reported in the literature, and it was only efficacious for small stones < 50 mm^2 [5].

The study by Alanee et al. compared the Medstone STS EH lithotriptor with its replacement at their institution, the Storz Modulith SLX EM lithotriptor, and results were similar for most stones [8]. Bhojani et al. compared their Storz Modulith SLX EM lithotriptor with its replacement, the LithoGold LG-380 EH lithotriptor in a community practice setting, and both machines yielded similar stone-free rates [11]. In these studies, the newer lithotriptors did not perform better than the older lithotriptors they replaced. In our study, the two lithotriptors we compared were contemporary models and patients underwent SWL concurrently at both hospital branches.

EM lithotriptors are small focus lithotriptors. They have very thin focal areas, which cover only part of the stone. In contrast, EH lithotriptors have a large focus which covers most of the stone area. Therefore, EM lithotriptors require more shocks than EH lithotriptors for adequate stone fragmentation. In Alanee et al.'s and Bhojani et al.'s studies, more shock waves at higher energy settings were delivered by the EM lithotriptors than the EH lithotriptors, resulting in longer treatment times but comparable success rates. In our study, the maximum number of shock waves delivered (4000 vs. 3500) and energy setting (24 vs. 22 kV) were higher in the EM group, but the stone-free rate was higher in the EH group.

The present study demonstrated a significantly higher overall stone-free rate and lower retreatment rate with the EH unit than with the EM unit for most stone sites and stone sizes. However, the EH and EM lithotriptors were comparable in the treatment of middle and lower ureteral stones in terms of stone-free and retreatment rates. This latter result was in agreement with those reported by Sheir et al. [10] and Bhojani et al. [11], but conflicted with Alanee et al.'s report that the EH lithotriptor was superior to the EM lithotriptor for lower ureteral stones [8]. The different results seen for middle and lower ureteral stones may be explained by the different skin-to-stone distances in the lower ureter compared to other ureteral segments. Gradual bladder distention during SWL may affect stone targeting by causing displacement of stones in the lower or middle ureter. In addition, awake patients may have more slight movements when placed in prone position than sedated patients, which may also result in stone displacement away from the target area during SWL. In our study, the number of patients with lower and middle ureteral stones was relatively small; therefore, a larger cohort of patients with stones in these locations is needed to confirm these results.

Our study did not show significantly better stone-free and retreatment rates for ureteral stones 1 cm or larger in size in the EH group. While the stone-free rate for these stones appeared to be higher in the EH group (42.8 vs. 20.0%), it was not statistically significant. This may be due to the small sample size.

Several studies showed that the stone-free rate increased with decreased shock wave frequency [12, 13]. Evan et al. also reported that slowing the frequency of the shock wave had a protective effect from kidney vascular injury [14]. At our institution, the frequency of shock waves was set at 120 shocks per minute in both lithotriptors due to surgical volume and manpower. However, only a few complications occurred. In agreement with the previous reports, the complication rates between the EH and EM groups were comparable.

The limitations of this study are (1) its retrospective nature; (2) the absence of strict guidelines for stent placement before SWL; (3) the small number of patients; (4) the lack of other predictors of SWL success (e.g., stone composition); (5) the lack of pain score data to evaluate post-SWL pain; and (6) the lack of CT scans in all cases to determine skin-to-stone distance and stone hardness.

Conclusions

The E3000 EH lithotriptor was more effective than the EM1000 EM lithotriptor in the treatment of kidney stones and upper ureteral stones. The EH lithotriptor was also superior for renal stones less than 2 cm and ureteral stones less than 1 cm in size. The two lithotriptors had comparable efficacies in the treatment of lower or middle ureteral stones and in the treatment of ureteral stones 1 cm or larger in size.

Author contributions CCL: project development, data collection, data analysis, and manuscript writing. WRL: data collection and data analysis. JMH: data collection. YCC: data collection. WKT: data collection. PKC: data collection. MC: project development, data analysis, and manuscript editing. AWC: manuscript editing.

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