

Bony Interference in Shockwave Lithotripsy: Implications for Patient Positioning

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Abstract

In shockwave lithotripsy (SWL), bones along the shockwave path can attenuate the energy delivered to the stone and interfere with fragmentation. We conducted a retrospective cohort study to determine whether bony interference identified during SWL is associated with reduced treatment success and increased need for further intervention. Patients receiving SWL as their primary treatment for a renal or ureteral calculus between January and December 2022 were reviewed. Bony interference was identified intra-operatively via fluoroscopy and pre-operatively via x-ray. The treatment outcomes studied were success rate (residual fragments < 2 mm), re-treatment rate, and complication rate. Multivariable logistic regression was used to quantify the association between bony interference and SWL treatment success. This study included 275 SWL patients, and intra-operative bony interference was observed in 41 (14.9%) cases. Intra-operative bony interference was associated with a significantly lower SWL success rate after a single treatment (22% with interference vs. 53% without interference) in univariable (OR = 0.25, $p = 0.001$) and multivariable (OR = 0.32, $p = 0.01$) logistic regressions. Intra-operative bony interference was also associated with a significantly higher re-treatment rate (OR = 2.50, $p = 0.008$). These findings highlight the clinical relevance of bony interference and suggest that patient positioning should be optimized to avoid bony structures. Prospective assessments are warranted to further develop and validate these positioning strategies.

Introduction

In shockwave lithotripsy (SWL), bones between the lithotripsy therapy head and the target stone can attenuate shockwave energy, reducing treatment efficacy [1, 2]. The acoustic attenuation coefficient of bone is significantly higher than that of other tissues, such as fat or muscle [3]. The pelvis may interfere with SWL for distal ureteral stones, while ribs and vertebrae may interfere with SWL for renal and proximal ureteral stones [4]. Bone is also known to interfere with other extracorporeal stone treatments, including burst-wave lithotripsy [5]. Modifications to patient positioning, such as the prone or oblique supine positions, may mitigate bony interference and improve stone fragmentation compared to supine positioning [6–11]. However, these modifications are not widely adopted, and renal and proximal ureteral stones are still typically treated supine to optimize acoustic coupling and avoid bowel gas. Furthermore, direct clinical evidence for the impact of bony interference on SWL outcomes has not been demonstrated, and the extent of this impact has not been quantified.

In this retrospective cohort study, we sought to determine whether bony interference identified during SWL is associated with reduced treatment success and increased need for further intervention. The results of this study may have important implications for patient positioning and selection for SWL.

Methods

Study Population

This study was approved by the University of British Columbia Clinical Research Ethics Board (H24-02641). Patients receiving SWL for a renal or ureteral calculus at Vancouver General Hospital between January and December 2022 were reviewed retrospectively. Study cohorts were defined by the presence or absence of bony interference seen on intra-operative fluoroscopy. Only patients undergoing their first treatment for the target stone were included. Patients were excluded from review if they had abnormal urinary tract anatomy, lacked a follow-up x-ray or computed tomography (CT) scan, received treatment for multiple stones on the ipsilateral side in the same session (and therefore received fewer shocks per stone to avoid tissue injury), or were younger than 18 years of age.

Shockwave Lithotripsy Procedure

All stones were diagnosed on non-contrast CT. Pre-operative stone localization was performed using same-day kidneys, ureters, and bladder (KUB) x-ray and intra-operative stone targeting was guided by biplanar fluoroscopy. Patients were positioned supine unless the stone was over the bony pelvis, in which case prone positioning was the standard of care. SWL procedures were performed using the Storz Modulith SLX-F2 lithotripter and were supervised by experienced endourologists. Treatment was delivered at 120 Hz, achieving 2500 shocks ramped to Storz energy level 6.0 for renal stones and 3000 shocks ramped to Storz energy level 8.0 for ureteral stones. Patients followed up with KUB x-ray and ultrasound imaging, and CT if x-ray findings were indeterminate.

Measurements

Bony interference was defined as any overlap on imaging between a bony structure and the target stone. Intra-operative and pre-operative bony interference were assessed for each patient (Fig. 1). Intra-operative bony interference was selected as the primary independent variable for our cohort analysis. Intra-operative fluoroscopy reflects the true shockwave pathway, whereas pre-operative x-ray does not account for respiratory motion or stone migration. Sources of bony interference included ribs, vertebrae (vertebral bodies and transverse processes), and the pelvis. The degree of bony interference was quantified as the proportion of the stone area occluded by an overlying bony structure.

Patient and stone characteristics were collected as covariates for multivariable analysis. Prone or supine positioning was documented. Patient age, sex, and body mass index (BMI) were collected from the electronic medical record. Stone side, location (kidney or ureter), size (maximal diameter, in mm), density (Hounsfield units, HU), and skin-to-stone distance (SSD) (cm) were measured from diagnostic CT images using axial slices in the bone window.

Post-SWL Outcomes

Stone-free status was classified as Grade A (no residual fragments), Grade B (Grade A plus residual fragments < 2 mm), or Grade C (Grade A or B plus residual fragments < 4 mm), determined by post-

operative x-ray or CT scan. The primary outcome for this study was SWL success, defined as Grade B stone-free status. Secondary outcomes included re-treatment with SWL or ureteroscopy (URS) and complications such as steinstrasse, hematoma, urosepsis, or tissue injury (e.g., bowel perforation).

Statistical Analysis

Statistical analysis was performed with R (V4.5.1) in RStudio (V2025.05.1). The required sample size for a significance level of 0.05 and 80% statistical power, with unbalanced groups at a ratio of 0.25, was determined *a priori* using power analysis for comparison of two proportions based on similarly designed studies in the literature [10].

Study cohorts were defined by the presence or absence of intra-operative bony interference. Baseline patient and stone characteristics were compared between the cohorts using Student's *t*-test for normally distributed continuous variables, the Wilcoxon rank-sum test for non-normally distributed continuous variables, Pearson's chi-squared test for categorical variables with cell counts > 5, and Fisher's exact test for categorical variables with cell counts < 5. Normality was determined using the Shapiro-Wilk test. Univariable logistic regressions were used to evaluate the association between each study covariate and the primary and secondary outcomes. Per convention, covariates with univariable $p < 0.20$ were included in the multivariable logistic regression model.

Results

Patient Demographics and Stone Characteristics

This study included 275 SWL patients. Baseline study characteristics are shown in Table 1. Intra-operative bony interference was observed in 41 (14.9%) cases and was not observed in any patients positioned prone ($p = 0.02$). Pre-operative bony interference was observed in 48 (17.5%) cases, and 24 (50%) of these interference cases persisted intra-operatively ($p < 0.001$). No other baseline characteristics differed significantly between the cohorts. The mean time between SWL and follow-up imaging was 3.7 ± 2.4 weeks in the cohort with interference and 3.2 ± 1.9 weeks in the cohort without interference ($p = 0.13$).

Table 1
Baseline patient and stone characteristics

	Total (n = 275)	Intra-operative bony interference absent (n = 234)	Intra-operative bony interference present (n = 41)	p-value
Patient characteristics				
Age (years), mean $\pm$ SD	56.3 $\pm$ 15.3	56.3 $\pm$ 15.5	56.3 $\pm$ 14.3	0.948
Sex				0.92
Male, n (%)	203 (73.8%)	173 (73.9%)	30 (73.2%)	
Female, n (%)	72 (26.2%)	61 (26.1%)	11 (26.8%)	
BMI (kg/m ²), mean $\pm$ SD	26.6 $\pm$ 4.8	26.4 $\pm$ 4.7	27.6 $\pm$ 5.5	0.248
Stone characteristics				
Stone side				0.55
Left, n (%)	146 (53.1%)	126 (53.8%)	20 (48.8%)	
Right, n (%)	129 (46.9%)	108 (46.2%)	21 (51.2%)	
Stone location				0.14
Kidney, n (%)	112 (40.7%)	91 (38.9%)	21 (51.2%)	
Ureter, n (%)	163 (59.3%)	143 (61.1%)	20 (48.8%)	
Stone size (mm), mean $\pm$ SD	7.6 $\pm$ 2.6	7.6 $\pm$ 2.7	7.9 $\pm$ 2.4	0.407
Stone density (HU), mean $\pm$ SD	812.0 $\pm$ 268.0	805.5 $\pm$ 278.0	849.1 $\pm$ 199.9	0.21
Skin-to-stone distance (cm), mean $\pm$ SD	11.3 $\pm$ 2.2	11.3 $\pm$ 2.3	11.4 $\pm$ 2.1	0.935
Patient position				0.02
Supine, n (%)	248 (90.2%)	207 (88.5%)	41 (100.0%)	
Prone, n (%)	27 (9.8%)	27 (11.5%)	0 (0.0%)	

	Total (n = 275)	Intra-operative bony interference absent (n = 234)	Intra-operative bony interference present (n = 41)	p-value
Patient characteristics				
Pre-operative bony interference				< 0.001
Absent, n (%)	227 (82.5%)	210 (89.7%)	17 (41.5%)	
Present, n (%)	48 (17.5%)	24 (10.3%)	24 (58.5%)	

Bony Interference and Treatment Outcomes

Results from univariable logistic regression of intra-operative bony interference against all study outcomes are shown in Table 2. SWL with intra-operative bony interference had a significantly lower success rate than SWL without interference (22.0% vs. 53.0%, OR = 0.25, $p = 0.001$). The overall rate of re-treatment was significantly higher in the presence of intra-operative bony interference (OR = 2.50, $p = 0.008$). Complication rates did not vary significantly between the cohorts.

Table 2
Association between bony interference and SWL outcomes

Stone-free status	Total (n = 275)	Intra-operative bony interference absent (n = 234)	Intra-operative bony interference present (n = 41)	Univariable OR (95% CI), <i>p</i> -value
Grade A, n (%)	119 (43.3%)	110 (47.0%)	9 (22.0%)	0.32 (0.14, 0.69), <i>p</i> = 0.004
Grade B, n (%)	133 (48.4%)	124 (53.0%)	9 (22.0%)	0.25 (0.11, 0.55), <i>p</i> = 0.001
Grade C, n (%)	151 (54.9%)	140 (59.8%)	11 (26.8%)	0.25 (0.12, 0.52), <i>p</i> < 0.001
Re-treatment				
Total, n (%)	96 (34.9%)	74 (31.6%)	22 (53.7%)	2.50 (1.28, 4.91), <i>p</i> = 0.008
SWL, n (%)	41 (14.9%)	31 (13.2%)	10 (24.4%)	2.11 (0.94, 4.73), <i>p</i> = 0.07
URS, n (%)	55 (20.0%)	43 (18.4%)	12 (29.3%)	1.84 (0.87, 3.89), <i>p</i> = 0.11
Complications				
Total, n (%)	11 (4.0%)	10 (4.3%)	1 (2.4%)	0.56 (0.07, 4.50), <i>p</i> = 0.59
Steinstrasse, n (%)	7 (2.5%)	6 (2.6%)	1 (2.4%)	0.95 (0.11, 8.10), <i>p</i> = 0.96
Hematoma, n (%)	3 (1.1%)	3 (1.3%)	0 (0.0%)	-
Urosepsis, n (%)	1 (0.4%)	1 (0.4%)	0 (0.0%)	-
Tissue injury, n (%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	-

Predictors of SWL Efficacy

Results from univariable and multivariable logistic regression of all covariates against the primary outcome, SWL success, are shown in Table 3. In the multivariable model, the effects of stone location

(OR = 1.99 in the ureter vs. the kidney, $p = 0.02$), stone density (OR = 0.82 per 100 HU increase, $p = 0.001$), and intra-operative bony interference (OR = 0.32 with interference present vs. absent, $p = 0.01$) remained significant predictors of SWL efficacy, while the effect of pre-operative bony interference did not (OR = 0.71 for interference present vs. absent, $p = 0.40$). No statistically significant interaction terms were identified.

Table 3

Adjusted effects of patient characteristics, stone characteristics, and bony interference on the likelihood of SWL success. Odds ratios are reported per unit increase for continuous variables, except stone density, which is reported per 100 HU increase

	Univariable OR (95% CI), p -value	Multivariable OR (95% CI), p -value
Patient characteristics		
Age (years)	0.98 (0.97, 1.00), $p = 0.03$	0.99 (0.97, 1.00), $p = 0.20$
Sex (reference: female)	1.24 (0.72, 2.12), $p = 0.44$	-
BMI (kg/m ²)	0.96 (0.91, 1.01), $p = 0.11$	0.99 (0.92, 1.06), $p = 0.72$
Stone characteristics		
Stone side (reference: left)	0.87 (0.54, 1.40), $p = 0.56$	-
Stone location (reference: kidney)	1.86 (1.14, 3.03), $p = 0.01$	1.99 (1.10, 3.64), $p = 0.02$
Stone size (mm)	0.80 (0.72, 0.89), $p < 0.001$	0.91 (0.81, 1.03), $p = 0.16$
Stone density (100 HU)	0.79 (0.71, 0.87), $p < 0.001$	0.82 (0.73, 0.92), $p = 0.001$
Skin-to-stone distance (cm)	0.93 (0.83, 1.03), $p = 0.17$	0.91 (0.78, 1.05), $p = 0.21$
Patient position (reference: supine)	1.38 (0.62, 3.06), $p = 0.43$	-
Pre-operative bony interference (reference: absent)	0.37 (0.19, 0.73), $p = 0.004$	0.71 (0.31, 1.57), $p = 0.40$
Intra-operative bony interference (reference: absent)	0.25 (0.11, 0.55), $p = 0.001$	0.32 (0.12, 0.76), $p = 0.01$

Bony Interference Characteristics

Intra-operative bony interference most often involved the posterior ribs (20 of 41 (48.7%) cases), followed by vertebrae (17 of 41 (41.6%) cases) and the pelvis (4 of 41 (9.7%) cases). Neither the bone type nor the degree of bony interference was significantly correlated with SWL success.

Discussion

In this study, we demonstrate that bony interference, measured intra-operatively using fluoroscopy, is independently associated with a lower SWL stone-free rate after adjustment for confounding by known predictors of SWL outcomes [12–14].

The effects of bony structures on shockwave delivery and stone fragmentation have been demonstrated in laboratory-based studies. For example, Olvera-Posada et al. evaluated SWL fragmentation using porcine lumbar vertebrae superimposed on plaster stone phantoms [15]. Compared to control stones, which were broken into small fragments, stones with bony interference had only superficial indentations or were fragmented into large pieces. Another study by Vergunst et al. found that porcine ribs can alter the shockwave waveform at the stone, thereby impacting fragmentation dynamics [16]. Our study provides clinical confirmation of these findings. We found that the success rate in patients with intra-operative bony interference was just 22%, while the overall success rate was 48.4%. Bony interference was also associated with higher overall re-treatment rates, suggesting that it may result in larger residual fragments that are less likely to be managed conservatively and more likely to require additional definitive intervention.

The effect size of bony interference can be contextualized using SSD, an established tissue variable associated with SWL outcomes [17]. While SSD did not factor significantly in our statistical analysis, increasing SSD is generally associated with reduced SWL efficacy, with reported odds ratios for SWL success as low as 0.49 when comparing high- and low-SSD groups [18–22]. Our adjusted odds ratio of 0.32 for intra-operative bony interference is comparable to these effect sizes, suggesting that, like SSD, bony interference may be considered an important tissue variable in SWL planning. Bone thickness and density may be investigated in future studies as potential modifiers of the bony interference effect [23, 24].

The clinical significance of bony interference suggests that patient positioning modifications to avoid bony structures may be warranted. Given that bony interference affects SWL throughout the kidneys and ureters, these patient positioning changes may need to be specific to different locations and bony structures. For distal ureteral stones affected by pelvic bones, the prone position minimizes the risk of bony interference and has demonstrated superior SWL outcomes compared to the supine position [6, 7]. Meanwhile, for renal and proximal ureteral stones affected by ribs and vertebrae, the prone position may offer minimal benefit due to bowel gas interference and increased SSD [8]. Oblique or rotated-supine positioning may be a solution in these cases, as it has demonstrated superior outcomes for both proximal and distal ureteral stones [9–11]. The effect of this intervention on treatment outcomes in bony interference should be studied prospectively.

Bony interference is most accurately assessed intra-operatively with fluoroscopy. Pre-operative imaging may identify patients at risk and guide operative planning. Pre-operative bony interference on KUB x-ray was a significant predictor of SWL success in univariable analysis, but not after multivariable adjustment. Furthermore, 24 of the 48 patients (50%) with pre-operative bony interference did not have

intra-operative bony interference, demonstrating that in practice, stone movement and changes in patient positioning may limit the reliability of predictions based on pre-operative imaging.

SWL efficacy did not depend on the degree of bony interference, defined as the proportion of stone area covered by the interposed bone on intra-operative fluoroscopy. This may be attributable to the use of two-dimensional imaging to assess bone position without considering bone depth. Interference observed on fluoroscopy may not accurately reflect the proportion of the acoustic field that is attenuated, as a bone located closer to the shockwave focus can cover a greater proportion of the shockwave cross-sectional area than a bone located closer to the skin [25]. Future studies may correlate intra-operative fluoroscopy with pre-operative CT to characterize the three-dimensional relationship between the shockwave, bones, and the target stone.

In addition to the limitations of fluoroscopic imaging, the retrospective design of this study limited methodological control over clinical decisions, such as patient selection, positioning, and stone targeting. Intra-operative fluoroscopy was used sparingly to minimize radiation exposure, but this also limited the ability to assess stone movement-induced variations in bony interference [26, 27]. This study was conducted at a single center using a single lithotripter model, which limits its generalizability to different patient populations or lithotripsy protocols. For example, some lithotripters have fixed therapy heads, while other lithotripters have mobile therapy heads that may help avoid bony interference. The association between bony interference and reduced SWL success is likely generalizable, but the effect size and its clinical implications should be interpreted within local contexts.

Conclusions

This study demonstrates that bony interference is associated with poorer SWL outcomes, suggesting that bony interference during SWL should be avoided whenever possible. This may include repositioning patients to avoid bony overlap and evaluating bony interference pre-operatively to inform operative planning and patient selection. Our findings are clinically actionable, as simple positioning modifications may reduce bony interference. Prospective studies incorporating these changes will help establish their role in routine practice.

Declarations

Ethics Approval

This study was approved by the University of British Columbia Clinical Research Ethics Board (H24-02641).

Informed Consent

Given the retrospective nature of this study, the requirement for individual consent to participate was waived by the University of British Columbia Clinical Research Ethics Board.

Competing Interests

The authors declare no competing interests relevant to the content of this article.

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Author Contribution

All authors contributed to conceptualization and design of the study. E.L. and A.A. performed data collection. E.L., A.A., B.C., and C.F. performed data analysis, wrote the manuscript, and prepared figure 1 and tables 1-3. V.W., R.P., B.C., and C.F. provided administrative support and supervision. All authors reviewed and edited the manuscript.

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Data Availability

The data generated in this study are stored in an institutional REDCap system and therefore are not publicly available. The data are available from the corresponding author upon reasonable request.

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Figures

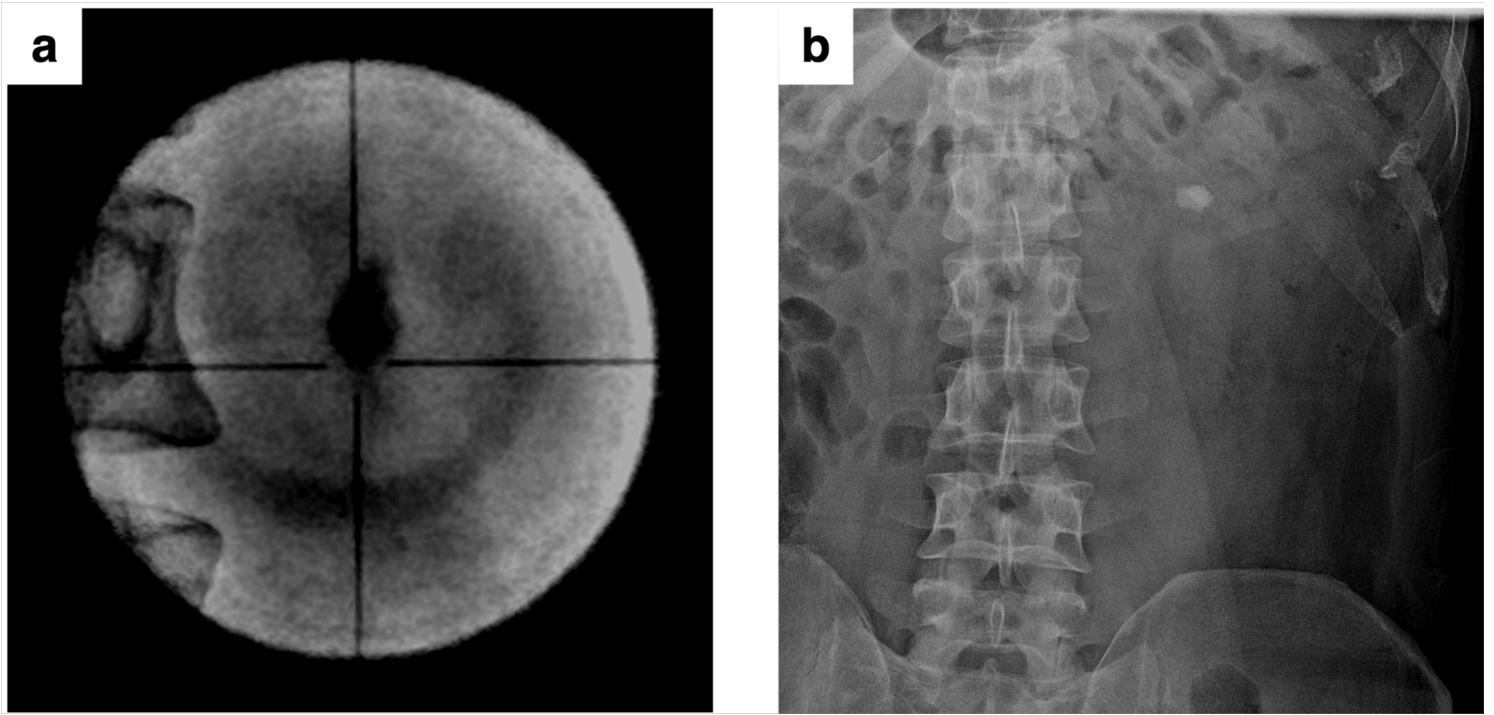


Figure 1

Examples of bony interference: (a) Intra-operative bony interference, on fluoroscopy, involving a vertebral transverse process and (b) pre-operative bony interference, on KUB x-ray, involving a posterior rib

Supplementary Files

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