Validation of a Functional Pyelocalyceal Renal Model for the Evaluation of Renal Calculi Passage While Riding a Roller Coaster

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Context: The identification and evaluation of activities capable of dislodging calyceal renal calculi require a patient surrogate or validated functional pyelocalyceal renal model.

Objective: To evaluate roller coaster facilitation of calyceal renal calculi passage using a functional pyelocalyceal renal model.

Methods: A previously described adult ureteroscopy and renoscopy simulator (Ideal Anatomic) was modified and remolded to function as a patient surrogate. Three renal calculi of different sizes from the patient who provided the original computed tomographic urograph on which the simulator was based were used. The renal calculi were suspended in urine in the model and taken for 20 rides on the Big Thunder Mountain Railroad roller coaster at Walt Disney World in Orlando, Florida. The roller coaster rides were analyzed using variables of renal calculi volume, calyceal location, model position on the roller coaster, and renal calculi passage.

Results: Sixty renal calculi rides were analyzed. Independent of renal calculi volume and calyceal location, front seating on the roller coaster resulted in a passage rate of 4 of 24. Independent of renal calculi volume and calyceal location, rear seating on the roller coaster resulted in a passage rate of 23 of 36. Independent of renal calculi volume in rear seating, calyceal location differed in passage rates, with an upper calyceal calculi passage rate of 100%; a middle calyceal passage rate of 55.6%; and a lower calyceal passage rate of 40.0%.

Conclusion: The functional pyelocalyceal renal model serves as a functional patient surrogate to evaluate activities that facilitate calyceal renal calculi passage. The rear seating position on the roller coaster led to the most renal calculi passages.

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In the United States each year, more than 300,000 patients seek emergency department care for kidney stones, or renal calculi.[1] Patient positional inversion, hydration, and external application of force to the body wall has been used to facilitate renal calculi passage with variable success.[2-5] Reports of spontaneous renal calculi passage associated with bungee cord jumping and roller coaster riding have been published in the foreign lay press.[6] The lifetime prevalence of kidney stones in men is approximately 11% and in women, 6%.[1]

Over several years, a notable number of our patients reported passing renal calculi spontaneously after riding the Big Thunder Mountain Railroad roller coaster at Walt Disney World's Magic Kingdom theme park in Orlando, Florida. The number of stone passages was sufficient to raise suspicions of a possible link between riding a roller coaster and passing renal calculi. One patient reported passing renal calculi after each of 3 consecutive rides on the roller coaster. Many patients reported passing renal calculi within hours of leaving the amusement park, and all of them rode the same roller-coaster during their visit.

The purpose of the current study was to validate this functional pyelocalyceal renal model and to provide clinical recommendations based on data generated.

Figure 1.
Validated ureteroscopy and renoscopy surgical simulator.

Methods

A high-fidelity adult ureteroscopy and renoscopy simulator (Ideal Anatomic) was modified and evaluated as a potential patient surrogate to study variables associated with renal calculi passage (*Figure 1*).[7,8] The behavior of the renal calculi within the pyelocalyceal renal model mimicked the clinical experience and outcomes as reported by patients anecdotally as well as according to the physiologic behavior of renal calculi in the calices. The simulator was adapted by remolding it in clear silicone to create a functional pyelocalyceal renal model able to permit direct inspection of calculi movement within the calyceal system (*Figure 2*). The ureter and partial bladder components of the Ideal Anatomic simulator were removed during the modification process to facilitate sealing the hollow portion of the renal component. The sealed model contained 3 calcium oxalate calculi with volumes of 4.5 mm^3, 13.5 mm^3, or 64.6 mm^3 suspended in urine. The renal calculi used in this study had been spontaneously passed from the patient whose computed tomographic urogram scan was used to create the original pyelocalyceal renal cast model.

Figure 2.
Functional pyelocalyceal renal model (silicone) modified from a validated ureteroscopy and renoscopy surgical simulator.

The roller coaster had twin tubular steel rails and it did not go upside-down. The maximum speed was 35 mph, and the model was subjected to sharp turns and quick drops during the ride, which lasted 2 minutes and 30 seconds. The roller coaster was made up of a railway train engine with no passenger seating and 5 passenger cars with 3 rows of seats and 2 to 3 passengers abreast in each car (*Figure 3*). While riding on the roller coaster, the pyelocalyceal renal model was seated in an anatomic position inside a padded backpack held against the back of the seat at renal height between the researchers.

The renal calculi were loaded into the calyceal system of the clear functional pyelocalyceal renal model, and their positions were documented. After each ride, the position of each stone was recorded and renal calculi were repositioned as needed. The renal calculi were positioned into their calyceal locations using rotation, external compression of the functional pyelocalyceal renal model, and direct percutaneous needle manipulation. A renal calculus was recorded as passed if it moved from a starting location in a renal calyx into the trap at the level of the ureteropelvic junction.

The pyelocalyceal renal model containing 3 calculi was taken for 20 rides on the roller coaster during the 2008 amusement park season. Seat assignment on the roller coaster was random and determined as a function of place in the waiting line. Stone distribution within the model was allocated so a renal calculus occupied each calyx during the trial.

Care was taken to protect and preserve the enjoyment of the other guests at the park. Before the park's Guest Services consented to our research project, researchers agreed to abide by the park's tenets of safety, show, courtesy, and efficiency.

Results

A total of 60 renal calculi rides on the roller coaster were analyzed using variables of renal calculi volume, calyceal location, renal model position on the roller coaster, and renal calculi passage. The functional pyelocalyceal renal model contained 3 renal calculi and completed 20 rides (*Table 1* and *Table 2*).

Raw data were gathered from the front seating (cars 1-3, rows 1-7) and rear seating (car 5, rows 13-15) of the roller coaster. Renal calculi were distributed within the pyelocalyceal renal model to provide data from all calyxes and calculi volumes. In 8 rides, the model was placed in the front seating (cars 1-3, rows 1-7), and in 12 rides, the model was placed in the rear seating (car 5, rows 13-15).

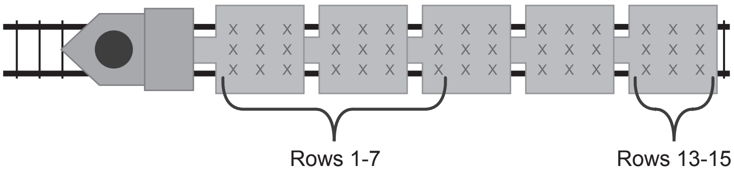

Figure 3.
Roller coaster seating for the functional pyelocalyceal renal model containing renal calculi suspended in urine.

The overall renal calculi passage rate in the front seating of the roller coaster, regardless of renal calculi volume or calyceal location, was 4 of 24 (16.67%). The overall renal calculi passage rate in the rear seating of the roller coaster, regardless of renal calculi volume or calyceal location was 23 of 36 (63.89%).

Front Seating on Roller Coaster

4.5-mm³ Renal Calculus

When starting in the lower calyx of the functional pyelocalyceal renal model, the 4.5-mm^3 renal calculus passed to the ureteropelvic junction region in 1 of 3 rides. Although starting 1 time in the upper calyx and 4 times in the middle calyx, the 4.5-mm^3 renal calculus never passed out of the calyx in which it was initially placed. The overall passage rate of the 4.5-mm^3 renal calculus in the roller coaster's front seating was 1 of 8 rides.

13.5-mm³ Renal Calculus

When starting in the middle calyx of the functional pyelocalyceal renal model, the 13.5 mm^3 volume renal calculus passed to the ureteropelvic junction region in 1 of 2 rides. Although starting 1 time in the upper calyx and 5 times in the lower calyx, this renal calculus never passed out of the calyx in which it was initially placed. The overall passage rate of the 13.5-mm^3 renal calculus in the roller coaster's front seating was 1 of 8 rides.

Table 1.
Passage of Renal Calculi in a Functional Pyelocalyceal Renal Model Placed in Front Section of Roller Coaster[a]

Location of Calculi in Calyx	Calculi Volume			Overall Passage
	4.5 mm^3	13.5 mm^3	64.6 mm^3	
Upper	0/1 (0)	0/1 (0)	2/7 (28.6)	2/9 (22.2)
Middle	0/4 (0)	1/2 (50.0)	…	1/6 (16.7)
Lower	1/3 (33.3)	0/5 (0)	0/1 (0)	1/9 (11.1)
Total	1/8 (12.5)	1/8 (12.5)	2/8 (25.0)	4/24 (16.7)

[a] Data are given as No. passed/No. of attempts (%).

Table 2.
Passage of Renal Calculi in a Functional Pyelocalyceal Renal Model Placed in Rear Section of Roller Coaster[a]

Location of Calculi in Calyx	Calculi Volume			Overall Passage
	4.5 mm^3	13.5 mm^3	64.6 mm^3	
Upper	4/4 (100)	4/4 (100)	4/4 (100)	12/12 (100)
Middle	3/3 (100)	1/4 (25.0)	1/2 (50.0)	5/9 (55.6)
Lower	1/5 (20.0)	2/4 (50.0)	3/6 (50.0)	6/15 (40.0)
Total	8/12 (66.7)	7/12 (58.3)	8/12 (66.7)	23/36 (63.9)

[a] Data are given as No. passed/No. of attempts (%).

64.6-mm^3 Renal Calculus

When starting in the upper calyx of the pyelocalyceal renal model, the 64.6-mm^3 renal calculus passed to the ureteropelvic junction region in 2 of 7 rides. Although starting 1 time in the lower calyx, this renal calculus never passed out of the lower calyx. It never started in the middle calyx. The overall passage rate of this renal calculus in the front seating was 2 of 8 rides.

Combined Passage by Calyceal Location

The combined passage rate of all renal calculus volumes from the upper calyx in the roller coaster's front seating was 2 of 9 rides. The combined passage rate of all renal calculus volumes from the middle calyx in the front seating was 1 of 6 rides. The combined passage rate of all renal calculus volumes from the lower calyx in the front seating was 2 of 8 rides.

Rear Seating on Roller Coaster

4.5-mm^3 Renal Calculus

The 4.5-mm^3 renal calculus passed to the ureteropelvic junction region in 4 of 4 rides when starting in the upper calyx of the pyelocalyceal renal model and in 3 of 3 rides when starting in the middle calyx of the pyelocalyceal renal model. Passage of the 4.5-mm^3 renal calculus occurred in 1 of 5 rides when starting in the lower calyx. The overall passage rate of this renal calculus in the roller coaster's rear seating was 8 of 12 rides.

13.5-mm³ Renal Calculus

The 13.5-mm³ renal calculus passed to the ureteropelvic junction region in 4 of 4 rides when starting in the upper calyx of the pyelocalyceal renal model. Passage of this renal calculus occurred in 1 of 4 rides from the middle calyx and in 2 of 4 rides from the lower calyx. The overall passage rate of this renal calculus in the roller coaster's rear seating was 7 of 12 rides.

64.6-mm³ Renal Calculus

The 64.6-mm³ renal calculus passed to the ureteropelvic junction region in 4 of 4 rides when starting in the upper calyx of the renal model. Passage of this renal calculus occurred in 1 of 2 rides from the middle calyx and in 3 of 6 rides from the lower calyx. The overall passage rate of the 64.6-mm³ renal calculus in the roller coaster's rear seating was 8 of 12 rides.

Combined Passage by Calyceal Location

The combined passage rate of all renal calculi volumes from the upper calyx in the rear seating was 12 of 12 rides. The combined passage of all renal calculi volumes rate from the middle calyx in the rear seating was 5 of 9 rides. The combined passage rate of all renal calculi volumes from the lower calyx in the rear seating was 6 of 15 rides.

Discussion

The Ideal Anatomic ureteroscopy and renoscopy surgical simulator was successfully modified for use as a patient surrogate in the study of factors responsible for renal calculi passage. Renal calculi pass preferentially from the upper calyxes in clinical practice, and small calculi located in the lower calyces may be difficult to move into the renal pelvis. The pyelocalyceal renal model was sensitive to changes in its location on the roller coaster as manifested with differential renal calculi passage. Renal calculi of various volumes and calyceal starting positions were passed regularly and reproducibly.

A renal calculus greater than 6 mm in diameter has about a 1% chance of spontaneous passage without intervention.[9] Persons with known renal calculi of a volume likely to cause ureteral obstruction or significant renal colic may wish to avoid the kinds of external forces evaluated in the current study. The majority of renal calculi less than 5 mm in diameter may be monitored; still, these calculi may grow in size over time.[10] Retained renal calculi after extracorporeal shock wave lithotripsy can enlarge over time, and the urinary stone recurrence rate approaches 50% at 10 years.[11] After extracorporeal shock wave lithotripsy with fragmentation of the renal calculi, riding in the rear car of a moderate-intensity roller coaster might facilitate fragment passage.

Many people in the United States probably live within a few hours' drive of an amusement park containing a roller coaster with features capable of dislodging calyceal renal calculi. However, physicians and their patients should consider renal calculi location and size as well as medical history. For example, renal calculi in the inferior pole have difficulty passing because of gravity, but the opposite effect occurs in the upper calyxes.[12] Once a patient has passed a renal calculus, regular riding on a moderate-intensity roller coaster may facilitate microscopic and very small (ie, the size of a grain of sand) calculi passage before symptomatic renal calculi can recur. Women with small renal calculi who are planning to become pregnant should consider riding moderate-intensity roller coasters before starting calcium and vitamin D supplements with prenatal vitamins to reduce the risk of complications from renal calculi in pregnancy.[13]

Limitations to the current study include the use of a renal model instead of real patients, testing the model on only 1 roller coaster, and using only 1 person's kidney stones. Also, the mechanisms behind the roller coaster's facilitation of kidney stone passage have yet to be determined. Additional pyelocalyceal renal models should be developed using computed tomographic urograms of patients with and without a history of renal calculi. The entire spectrum of renal calculi volume, shape, and com-position deserves study and evaluation. Other amusement theme park rides should be evaluated to determine the exact forces most likely to dislodge calyceal renal calculi before the stones reach obstructive volume.

Initial attempts to mold and create a pyelocalyceal renal model made of ballistic jelly resulted in models unable to endure the rigors of repeated roller coaster rides. Bovine and porcine renal models were deemed impractical as patient surrogates for study, owing to ambient temperature and the inappropriate display of such material in a family-friendly amusement park.

Conclusion

The clear silicone functional pyelocalyceal renal model, modified and remolded from a peer-reviewed ureteroscopy and renoscopy surgical simulator, has been validated both as an anatomic surgical trainer and functional patient surrogate to evaluate activities facilitating passage of renal calculi. The pyelocalyceal renal model accurately reproduced the clinical experience of renal calculi passage relating to calculi volume and calyceal starting position. The relationship between structure and function is a core principle of osteopathic medicine. Obstruction of the upper urinary tract by a calculus demonstrates the profound synergy between anatomy and physiology.

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Author Contributions

All authors provided substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; all authors drafted the article or revised it critically for important intellectual content; all authors gave final approval of the version of the article to be published; and all authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Urinary tract stones. In: Litwin MD, Saigal CS, eds. *Urologic Diseases in America*. Washington, DC: Dept of Health and Human Services, Public Health Service, National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases; 2012.
2. Brownlee N, Foster M, Griffith DP, Carlton CE Jr. Controlled inversion therapy: an adjunct to the elimination of gravity-dependent fragments following extra corporeal shock wave lithotripsy. *J Urol.* 1990;143(6):1096-1098.
3. Pace KT, Tariq N, Dyer SJ, Weir MJ, D'A Honey RJ. Mechanical percussion, inversion, and diuresis for residual lower pole fragments after shock wave lithotripsy: a prospective, single blind, randomized controlled trial. *J Urol.* 2001;166(6):2065-2071.
4. D'A Honey RJ, Luymers J, Weir MJ, Kodama R, Tariq N.. Mechanical percussion inversion can results can result in relocation of lower pole stone fragments after shock wave lithotripsy. *Urology.* 2000;55(2):204-206.
5. Rodrigues Netto N Jr, Claro JF, Cortado PL, Lemos GC. Adjunct controlled inversion therapy following extracorporeal shock wave lithotripsy for lower pole calyceal stones. *J Urol.* 1991;146(4):953-954.
6. Roller coasters newest 'cure' for kidney stones? *Taiwan Today News*. February 20, 2009. http://www.taiwantodaynews.com/index.php/roller-coasters-newest-cure-for-kidney-stones/. Accessed August 25, 2016.
7. White MA, DeHaan AP, Stephens DD, Maes AA, Maatman TJ. Validation of a high fidelity adult ureteroscopy and renoscopy simulator. *J Urol.* 2010;183(2):673-677. doi:10.1016/j.juro.2009.10.013.
8. Mitchell MA. *The IDEAL Renal Model:Development and Determination of Face Validity of Novel Model for the Study of Renal Calculus Passage*. Lansing MI: Michigan State University, College of Osteopathic Medicine, Statewide Campus System, Sparrow Health System; 2009.
9. Miller OF, Kane CJ. Time to stone passage for observed ureteral calculi: a guide for patient education. *J Urol.* 1999;162(3 pt 1):688-691.
10. Segura JW, Preminger G M, Assimos DG, et al. Ureteral stones clinical guidelines panel summary report on the management of ureteral calculi. *J Urol.* 1997;158(5):1915-1921.
11. Carr LK, D'A Honey J, Jewett MA, Ibanez D, Ryan M, Bombardier C. New stone formation: a comparison of extracorporeal shock wave lithotripsy and percutaneous naphrolithtomy. *J Urol.* 1996;155:1565-1567. doi:10.1016/S0022-5347(01)66127-5.
12. Kidney stones. American Urological Association website. http://www.auanet.org/education/kidney-stones.cfm. Accessed September 12, 2016.
13. Semins MJ, Matlaga BR. Management of urolithiasis in pregnancy [review]. *Int J Womens Health.* 2013;5:599-604. doi:10.2147/IJWH.S51416.