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The Impact of Pelvicaliceal Anatomical Variation between the Stone-Bearing and Normal Contralateral Kidney on Stone Formation in Adult Patients with Lower Caliceal Stones

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ABSTRACT

Objective: We aimed to investigate the effect of pelvicaliceal anatomical differences on the etiology of lower caliceal stones.
Materials and Methods: Records of adult patients between January 1996 and December 2005 with solitary lower caliceal stone were reviewed. After exclusion of patients with hydronephrosis, major renal anatomic anomalies, non-calcium stones, history of recurrent stone disease and previous renal surgery, 78 patients were enrolled into the study. Lower pole infundibulopelvic angle (IPA), infundibulovertebral angle (IVA), infundibular length (IL), width (IW), number of minor calices and cortical thickness of the lower pole together with other caliceal variables obtained from the whole pelvicaliceal anatomy of both stone-bearing and contralateral normal kidneys were measured from intravenous pyelogram of the patients. Total pelvicaliceal volume was also calculated by a previously described formula for both kidneys.
Results: There were statistically significant difference between two kidneys in terms of IW ($p < 0.001$) and IL ($p = 0.002$) of the upper calyx, IW ($p = 0.001$) and IVA ($p < 0.001$) of the lower calyx), pelvicaliceal volume ($p < 0.001$), IPA of middle calyx ($p = 0.006$) and cortical thickness over the lower pole ($p < 0.001$). However there was no difference between stone-bearing and contralateral normal kidneys in terms of lower pole IPA ($p = 0.864$) and IL ($p = 0.568$).
Conclusion: Pelvicaliceal volume but not lower caliceal properties seem to be a risk factor for stone formation in lower calyx.

***Key words**: kidney calculi; etiology; kidney pelvis; kidney calices; anatomy*
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INTRODUCTION

Urinary stone disease has afflicted humankind since antiquity. Epidemiological data show an increase in prevalence and incidence rates. The prevalence of this disease has been estimated to be at 13% for adult men and 7% for adult women in the United States (1). The impact of epidemiologic intrinsic (genetics, age and sex) and extrinsic (geography, climatic and seasonal factors, water intake, occupation, diet and stress) factors, urine physical chemistry and inhibitors which play a role on crystal formation, growth and aggregation on the etiology of stone formation have been evaluated extensively in the literature, however the exact mechanism of stone formation remains unclear (2,3).

Pelvicaliceal anatomical variations in stone-bearing kidneys may also play a role in the etiology, however studies, which investigate pelvicaliceal anatomical differences, are generally interested on stone clearance of lower caliceal stones after shock wave lithotripsy (SWL) rather than its etiologic role. In these studies, several anatomical factors, such as infundibular length, width and infundibulopelvic angle were measured and lower pole ratio was calculated from pretreatment intravenous urogram and most studies concluded that caliceal anatomy was an important risk factor for lower pole stone clearance after SWL (4-6). On the other hand, the effects of pelvicaliceal anatomy on stone formation was not well evaluated up to date. If we consider that the all risk factors for stone formation are similar for both kidneys on a patient, it is very difficult to explain why a calculus is primarily formed in a single calyx but not in another calyx of both kidneys only by metabolic factors. From this point of view, it is very logical to consider that different pelvicaliceal properties among normal and stone-bearing kidneys are the key factors for the lateralization of the stone and also constitute a risk factor for their etiology. In the light of the aforementioned points, our aim in this study was to investigate the probable effect of pelvicaliceal anatomical differences between lower caliceal stone-bearing and normal contralateral kidney on the etiology of stone formation.

MATERIALS AND METHODS

The records of adult patients with solitary lower caliceal stone between January 1996 and December 2005 were reviewed for this retrospective study. After exclusion of patients with hydronephrosis, major renal anatomic anomalies (horseshoe, pelvic and malrotated kidney, bifid pelvis, bifid ureters, ectopic pelvic fusion anomaly), non-calcium stones, history of recurrent stone disease and previous renal surgery, 78 patients were enrolled into the study.

The mean age was 44.5 (range: 21 - 65) years. All the patients had intravenous pyelogram (IVP) available for review. The lower pole infundibulopelvic angle (IPA), infundibular length (IL) and width (IW) of both the stone-bearing and contralateral normal kidneys were measured from IVP of the patients, as described by Elbahnasy et al. (6). These variables were also calculated for upper and middle calices with modification of the same method to these caliceal structures. In addition, infundibulovertebral angle (IVA) as described by Srivastava et al. (7), cortical thickness over the lower pole and the number of minor calices were determined for both stone-bearing and contralateral kidneys. Surface area of the renal collecting system was measured from IVP of the patients using a 1 mm^2 grid, on which the borders and diameters of the pelvicaliceal system were marked. Thus, the surface area of the renal collecting system was calculated by counting the enclosed grid squares. Surface area estimates obtained by three of the study members showed less than 5 percent variability for the same areas. Also, a formula defined as 0.6 $(area)^{1.27}$ was used to calculate the total pelvicaliceal volume of both kidneys (8). Mann-Whitney U and chi-square tests were used for the statistical evaluation of both kidneys' pelvicaliceal parameters.

RESULTS

There were 35 patients with stones on left side and 43 patients on right side. Comparison of the anatomical variables between the stone-bearing and normal kidneys were shown in Table-1. The lower caliceal IPA of the stone-bearing kidney when compared to the normal contralateral kidney was more acute, equal and wider in 53.7%, 2.5% and 43.8% of the patients, respectively. The pelvicaliceal volume of the stone-bearing side ranged from 752 to 6264,2 mm^3 (mean 2569,85) and the difference of the pelvicaliceal volumes of both sides was statistically significant ($p < 0.001$). There was a statistically significant difference in IW and IL of the upper calyx between stone-bearing and contralateral normal kidneys ($p < 0.001$) ($p = 0.002$). The difference in terms of the middle calyx IPA of the stone-bearing and non-stone-bearing contralateral side was also statistically significant ($p = 0.006$). Again, lower pole IVA, IW and cortical thickness of the lower pole were significantly different ($p < 0.001$) ($p = 0.001$) ($p < 0.001$). However, no difference was found in terms of IPA and IW of lower calyx.

***Table 1** – Comparison of pelvicaliceal anatomical variables between the stone-bearing and normal contralateral kidney.*

Variable	Stone-bearing Kidney (Range)	Contralateral Normal Kidney (Range)	p Value
Lower IPA	56.62 (0-144)	56.84 (4- 180)	0.864
Middle IPA	101.28 (20-145)	110.57 (40-155)	0.006
Upper IPA	165 (0-214)	171.19 (16-220)	0.36
Lower IL (mm)	8.88 (1-20)	9.6 (1-25)	0.568
Middle IL (mm)	7.51 (2-18)	7.67 (1-17)	0.725
Upper IL (mm)	9.82 (2-24)	12.28 (2-30)	0.002
Lower IW (mm)	5.62 (1-15)	3.92 (1-12)	0.001
Middle IW (mm)	3.05 (1-10)	2.71 (1-10)	0.208
Upper IW (mm)	4.19 (1-14)	3.01 (1-10)	< 0.001
Lower IVA	33.11 (9-78)	40.66 (10-86)	< 0.001
Number of minor calices	2.12 (1-4)	2.02 (1-3)	0.275
Lower pole cortical thickness (mm)	23.82 (14-36)	27.23 (16-37)	< 0.001
Pelvicaliceal Volume (mm^3)	2569,85 (752-6264,2)	1824,94 (423,4-3997,3)	< 0.001

IPA = infundibulo pelvic angle; IL = infundibular length; IW = infundibular width; IVA = infundibulumvertebral angle.

DISCUSSION

Studies investigating the pathophysiology of urinary stone disease in anatomically normal kidneys generally focus on metabolic risk factors. However, metabolic factors alone are not sufficient to explain both unilateral stone disease and lower caliceal dominance. Some non-metabolic causes like sleep posture have been investigated to explain unilateral urolithiasis (9), but this hypothesis is also unsatisfactory for lower caliceal stones. Also, recurrent stone formation occurs usually in the same calyx and this finding based on our experiences supports our thought that some caliceal properties could play a critical role on stone formation.

The investigations of the relationship between pelvicaliceal anatomical features and urolithiasis started with the pioneering study of Sampaio & Aragão (4). After that, several studies analyzed the pelvicaliceal factors although these studies were generally interested in stone clearance of lower caliceal stones after SWL rather than in its etiologic role (5,6,10). In these studies, several anatomical factors, such as infundibular length, width and infundibulopelvic angle were measured and lower pole ratio was calculated on pretreatment intravenous urogram. Sampaio & Aragão concluded that an angle of less than 90-degrees between lower pole infundibulum and pelvis, multiple calyces and a caliceal width < 4 mm might lead to retention of residual stones in lower caliceal group after lithotripsy (4). Similarly most studies agreed that the caliceal anatomy was an important risk factor for lower pole stone clearance after SWL (5,6), however opposite opinions also exist (10).

In this study, our aim was to determine the probable effect of intrarenal anatomic variations on the etiology of lower caliceal stones and we evaluated the whole pelvicaliceal specifications of the stone-bearing and normal contralateral kidneys of 78 adult patients with unilateral lower caliceal stones. However, our results were somewhat confusing. Although there was a statistically significant difference in middle caliceal IPA ($p = 0.023$), upper caliceal IL and IW ($p = 0.025$) ($p = 0.029$) and lower caliceal IW ($p = 0.001$) between normal and stone-bearing kidneys, there were no difference in lower caliceal IL and IPA. Although gravitational factor might be more effective than the effect of the upper or middle caliceal variations on stone formation, these findings are also inadequate to explain the lateralization of the stone unless the stone exists in this defective upper or middle calyx. On the hand, there are only few studies, which focus on the etiologic role of these intrarenal anatomical factors (11,12). Gökalp et al. compared 119 lower caliceal stone-forming kidneys with 40 healthy controls and they concluded that lower pole IPA was not an important factor for stone formation in lower calyx similar to our study (11).

They found statistical significant difference in terms of lower infundibulum diameter and lower caliceal length. But their study group was different from our study group in that they compared the intrarenal anatomical parameters of the stone forming kidney with the normal kidney of healthy controls. The important paradox on this comparison was that the two kidneys were not under the similar metabolic conditions, while in our study the stone-bearing and control kidneys were under same metabolic load. In another study, Nabi et al. evaluated 100 consecutive patients with lower caliceal stones and they found that lower pole IPA was more acute in 74% of cases in stone-forming side than the normal contralateral kidney (12). They concluded that IPA was a significant risk factor for lower caliceal stones. However, they did not evaluate the factors other than IPA and IW of lower calyx. Also, they did not mention the age distribution of their patient group since pediatric and adult patients could have different intrarenal anatomies. When we consider the stone clearance after SWL in lower caliceal stones, we demonstrated different stone-free rates in pediatric and adult patients according to their different pelvicaliceal features (13) and this difference might also have a role on stone formation.

Interpretation of pelvicaliceal anatomy from two-dimensional IVP is very difficult. A large series of three-dimensional endocasts of the kidney collecting system showed that the superior pole was drained by a single caliceal infundibulum in 98% of cases where as the inferior pole was drained by paired calices arranged in two rows in 58% of cases and by a single caliceal infundibulum in only 42% of cases (14,15). Moreover, some kidneys may have even more complex anatomy with atypical minor caliceal structures although we did not find any significant difference between the number of minor calices at lower pole. However, main lower caliceal infundibulum still seems to be the major factor for lower caliceal drainage. Our results showed statistical difference in lower caliceal IW but not in IL. These factors can change among patients and complicate to reach a final conclusion so all lower caliceal features should be accounted together. Because of this fact, studies that can be performed with 3 dimensional scanning could be more comprehensive. On the other hand, there were no baseline data to compare the pelvicaliceal variations and there would be a similar variation between 2 healthy kidneys. However, if there is an additional underlying metabolic factor, these anatomic differences might be a complementary factor on stone formation.

Another important point on interpretation of pelvicaliceal variations is the different measurement techniques and interobserver variations. Proper assessment of lower caliceal features seems to be a particular problem because several authors described different methods (6,16,17). A recent study showed that there were high interobserver variations among different techniques (18). We performed our measurements with the method described by Elbahnasy et al. (6) and the mean of the measurements by three different members of the study was accepted as the study data to eliminate the effect of intraobserver variations, which can also affect the results. Again, the imaging quality should be taken into account to achieve the best reliable data.

On the other hand, crystals must remain some time in pelvicaliceal system to form urinary stones and Schulz found that patients with urolithiasis are characterized by larger areas of renal pelvis or calyx on urogram (19). He hypothesized that larger pelvicaliceal system dimensions and higher ramification was the etiology of stone formation assuming that both healthy people and urolithiasis patients excrete similar volumes of urine. In addition, in the above study, it was estimated that the duration of stay for the urine might be up to 20 times longer in urolithiasis patients when compared to normal people. The stagnation and retention of crystals is at least as important as the formation of the crystals. In our study, the mean pelvicaliceal volume of the stone-forming and the normal kidneys were 2569,85 (752-6264,2) and 1824,94 (423,4-3997,3) mm^3, respectively ($p < 0.001$). The difference between these two groups in our study is a finding that parallels with the aforementioned hypothesis. We excluded all patients with hydronephrotic systems or any kind of caliceal dilations from the study so the large pelvicaliceal volumes are not related with obstruction but seem to be an anatomic specification of the affected kidney. Some reasons for large unilateral pelvicaliceal volume such as prior undetermined silent stone episode, complex renal anatomy with multiple calices or factors that affected the kidney at the evolution phase during childhood can be speculated. No matter what the reason was, the larger pelvicaliceal volumes of the stone-bearing kidney might be the evidence of urine stagnation although this should be confirmed with diuretic renograms to exclude any obstruction. Even if the longer stay of urine in the renal collecting system is not the sole factor, longer stay of crystals in a supersaturated media may cause calculi when a nidus exists. Although some lithogenesis can begin within the tubules, static condition of the lower calyx may be a complementary factor for lower caliceal stone etiology.

Concluding, our result shows that the etiology of stone formation does not depend solely on the lower pole pelvicaliceal anatomy in patients with lower caliceal stones but rather confirm the multifactorial etiology responsible for stone formation in the urinary tract. Larger pelvicaliceal volumes may result in impairment of drainage of the lower caliceal system and play a subtle role during the beginning of the nucleation process. The statistical significance of lower IW could not though be very important alone without statistical significance of lower IL and IPA, it can rather be a variant of larger pelvicaliceal system. Although we found significant differences in middle IPA, upper IL and IW between the stone bearing and normal contralateral kidneys, etiologic role of these middle and/or upper caliceal anatomical variations were uncertain. From this point of view, we can conclude that pelvicaliceal volume and lower caliceal IW seem to be risk factors for stone formation in lower calyx, however, all caliceal features should be accounted together to individualize the situation in each case.

CONFLICT OF INTEREST

None declared.

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EDITORIAL COMMENT

The high prevalence of nephrolithiasis has lead to significant interest in determining risk factors for stone formation. Most studies have focused on metabolic causes to identify risk factors for stone formation. This study by Kupeli et al. evaluates the relationship of pelvicaliceal anatomy and risk for lower caliceal stone formation. They found the stone-bearing kidney had a higher pelvicaliceal volume than the contralateral "normal" kidney controlling for obstruction, but no clear association was found with regard to IPA, IL, IW or IVA. The authors should be commended for attempting to identify anatomic risk factors for stone formation. However, there are several potential limitations of their study that may impact their conclusions.

First, the authors excluded patients with recurrent stones. If an anatomic variation is associated with an increased the risk of stone formation then the impact of this factor should be most evident in patients with recurrent and not first time stone-formers. It has been suggested that some anatomic abnormalities associated with stasis may contribute to an increased risk of stone-formation such as noted by the authors (hydronephrosis, UPJ obstruction, horseshoe kidney, etc) and does point to the importance of imaging such as intravenous pyelogram in the evaluation of stone-formers.

Although anatomic factors may contribute to the likelihood of forming a stone, the actual clinical usefulness of identifying these abnormalities is questionable. Unless one plans to screen the population to identify those harboring an anatomic abnormality that places them at increased risk of stone formation and then treatment them prophylactically without them having a stone, this information may be of limited value. The importance of the work of Sampaio and others in evaluating anatomic variations was to help guide treatment in patients with stones.

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EDITORIAL COMMENT

Since the pioneering work of Sampaio & Aragao (1), who introduced the concept of inferior pole collecting system anatomy, impacting the results of shock wave lithotripsy (SWL) for lower pole renal calculi, many clinical series have been published on this topic. The debate on the role of various anatomical features, on stone clearance after SWL, is still on going and far from being resolved.

Subsequently, there have been only a handful of articles looking at renal collecting system anatomy, especially lower pole caliceal anatomy, and its probable etiological role in lower caliceal stone formation. The most commonly sited significant anatomical features in these studies remain to be that of acute infundibulo-pelvic angle (IPA), greater infundibular length (IL) and smaller infundibular width (IW). The authors in this study compared the normal kidney to the contralateral stone forming side, and with this design, they were able to control for known confounding patient factors such as urine output and metabolic load. It is also commendable that they have taken much effort to minimize inter-observer variability in their measurement techniques. Interestingly, in contrast to the other studies, even with one of similar design, this study found that a larger mean pelvicaliceal volume and IW, rather than the other common lower caliceal anatomical features, appear to be the possible risk factors for lower caliceal stone formation. As hypothesized by Schulz (2), reduced flow rates and urine stagnation associated with larger pelvicaliceal dimensions could play a part in urinary calculi formation, seemingly providing a basis for the authors' current postulations, in this study.

However, it must be borne in mind that measurements of anatomical factors in many studies so far, have been made on a 2-dimensional radiograph, which may not accurately reflect the true 3-dimensional anatomical structure of the renal collecting system, and fraud with high observer variability. Furthermore, the fact that the renal collecting system is one of dynamic rather than a static geometric structure, and that mainly static imaging techniques are used to assess these anatomical factors, introduces a significant confounding factor in studies of this kind. Unless novel use of dynamic imaging studies are made to determine actual urinary drainage, and until a clearer consensus appears in literature, it can only be said that significant renal anatomical factors that predispose to lower caliceal stone formation are yet to be determined, and further investigation in this area should be carried out.

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EDITORIAL COMMENT

It is becoming increasingly evident that urolithiasis is a group of disorders rather than a single disease. Despite extensive study, we still do not have clear answers about the etiology of urinary stone disease. Anatomical factors could play a role in causation, although, their exact place within the context of a unified hypothesis remains unclear.

This study compared anatomical variables of collecting system volume, and individual caliceal group morphology between stone-bearing and normal contralateral kidney in 78 patients. The data showed that in the stone bearing kidney the overall collecting system volume is significantly greater, the lower pole cortex is thinner, the lower infundibulovertebral angle is smaller and the lower infundibular width is greater compared to the normal contralateral kidney. They also found that stone bearing kidneys had a smaller middle infundibulopelvic angle, as well as a shorter and wider upper infundibulum. The authors conclude that pelvicaliceal volume and lower infundibular width are risk factors for stone formation in the lower pole calices, while the significance of other findings is uncertain.

Although the paper does provoke thought, solid evidence for stagnation of urine in the stone-bearing kidney is lacking. A larger pelvicaliceal system volume does not necessarily translate into urine stagnation in the collecting system without functional evidence of delayed drainage. The role of a wider lower pole infundibulum in the causation of lower pole calculi also remains unclear. The thinner lower pole cortex could be an interesting observation and could be a cause or an effect of the stone. A scarred pyelonephritic group of calices may be associated with stone formation.

The collecting system of the kidney is a dynamic rather than a static geometrical structure and that fact will remain a confounding factor in studies of this nature, unless some kind of novel scintigraphic study can be used to determine actual drainage from individual components of the collecting system. In addition, the intrarenal caliceal anatomy is more complex than is evident from a two-dimensional IVP film, in terms of how minor calices drain into the major caliceal group or even into the renal pelvis.

Clearly, more work is needed to study the complex anatomical and functional features of stone bearing kidneys and calices for a better understanding of the interplay between anatomical and metabolic factors in the etiopathogenesis of urinary calculi.

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