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### Authors

Miller, Joe  
Durack, Jeremy C  
Sorensen, Mathew D  
et al.

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# Renal Calyceal Anatomy Characterization with 3-Dimensional In Vivo Computerized Tomography Imaging

Joe Miller,\* Jeremy C. Durack,† Mathew D. Sorensen, James H. Wang and Marshall L. Stoller‡

From the University of California-San Francisco (JM, MLS), San Francisco, California, Memorial Sloan-Kettering Cancer Center (JCD), New York, New York, University of Washington School of Medicine (MDS), Seattle, Washington, and University of Nevada School of Medicine (JHW), Reno, Nevada

### Abbreviations and Acronyms

3D = 3-dimensional  
AP = anteroposterior  
CT = computerized tomography  
MIP = maximum intensity projection  
ML = mediolateral  
PNL = percutaneous nephrolithotomy

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\* Correspondence: Department of Urology, 400 Parnassus Ave., Room A-632, San Francisco, California 94143 (telephone: 415-476-0331; FAX: 415-476-8849; e-mail: millerj@urology.ucsf.edu).

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For another article on a related topic see page 726.

**Purpose:** Calyceal selection for percutaneous renal access is critical for safe, effective performance of percutaneous nephrolithotomy. Available anatomical evidence is contradictory and incomplete. We present detailed renal calyceal anatomy obtained from in vivo 3-dimensional computerized tomography renderings.

**Materials and Methods:** A total of 60 computerized tomography urograms were randomly selected. The renal collecting system was isolated and 3-dimensional renderings were constructed. The primary plane of each calyceal group of 100 kidneys was determined. A coronal maximum intensity projection was used for simulated percutaneous access. The most inferior calyx was designated calyx 1. Moving superiorly, the subsequent calyces were designated calyx 2 and, when present, calyx 3. The surface rendering was rotated to assess the primary plane of the calyceal group and the orientation of the select calyx.

**Results:** The primary plane of the upper pole calyceal group was mediolateral in 95% of kidneys and the primary plane of the lower pole calyceal group was anteroposterior in 95%. Calyx 2 was chosen in 90 of 97 simulations and it was appropriate in 92%. Calyx 3 was chosen in 7 simulations but it was appropriate in only 57%. Calyx 1 was not selected in any simulation and it was anteriorly oriented in 75% of kidneys.

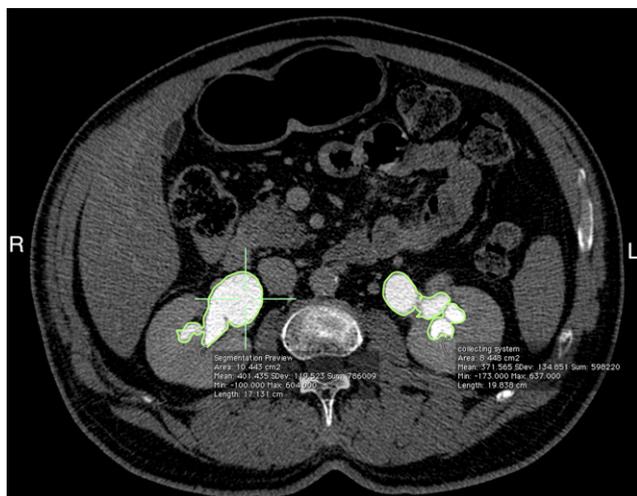
**Conclusions:** Appropriate lower pole calyceal access can be reliably accomplished with an understanding of the anatomical relationship between individual calyceal orientation and the primary plane of the calyceal group. Calyx 2 is most often appropriate for accessing the anteroposterior primary plane of the lower pole. Calyx 1 is most commonly oriented anterior.

**Key Words:** kidney; calculi; nephrolithotomy, percutaneous; imaging, three-dimensional; anatomy

SELECTION of an appropriate calyx for percutaneous renal access is critical to the performance of PNL. A thorough understanding of 3D renal calyceal anatomy is required to accurately interpret intraoperative imaging and accomplish the procedure in a safe, effective manner. Unfortunately, the anatomical evidence in the historical and contem-

porary literature is contradictory and incomplete.

Beginning in 1901 with the anatomical drawings by Brödel<sup>1</sup> and culminating with axial CT images,<sup>2</sup> the orientation of the lateral and medial calyces has been debated without resolution. More importantly, most groups have emphasized the orientation of



**Figure 1.** Renal collecting system segmentation

individual calyces, while failing to address the primary plane of the calyceal groups and the crucial relationship between the two.

We report the calyceal anatomy of 100 kidneys obtained from state-of-the-art in vivo 3D CT renderings. We present the results of simulated lower pole target calyceal selection for PNL based on our findings. These data may improve the safety and efficacy of PNL by contributing to the understanding of renal calyceal anatomy.

## MATERIALS AND METHODS

### Imaging

The institutional committee on human research approved this study with a waiver of informed consent. A total of 60 CT urograms from 2004 to 2011 were randomly selected from our archives. All imaging was performed on Light-Speed CT scanners (General Electric Healthcare, Princeton, New Jersey) at 120 kV with auto-mA calculations based on scout imaging (150 to 800 mA).

Each patient received 10 mg furosemide intravenously at least 15 minutes before scanning. Before the administration of intravenous contrast material a 5 mm first phase helical scan was performed with the patient prone. At the second imaging phase 1.25 to 2.50 mm helical scans were obtained with the patient supine 80 seconds after contrast injection. Third phase imaging consisted of 1.25 to 2.50 mm helical scans performed with the patient supine 10 minutes after contrast injection. Studies with extensive artifacts or kidneys with large cysts, masses, or surgical or traumatic distortion of the renal collecting system were excluded from analysis.

### Image Processing

All image processing was performed on a Mac Pro® quad core work station. From raw CT data we first used OsiriX Imaging Software (Pixmeo, Geneva, Switzerland), a 3D growing region segmentation tool, to isolate the collecting

system from the kidney parenchyma and vasculature. This was accomplished by manually placing a seed point in the center of each renal collecting system on delayed phase axial CT images (fig. 1). The software threshold algorithm was used to determine the boundaries of the calyces, renal pelvis and ureter by comparing the intensity of the pixels of the original seed point to the intensity of adjacent pixels within an extended polygonal region of interest. Complete segmentation was confirmed by visual inspection of the selection boundaries.

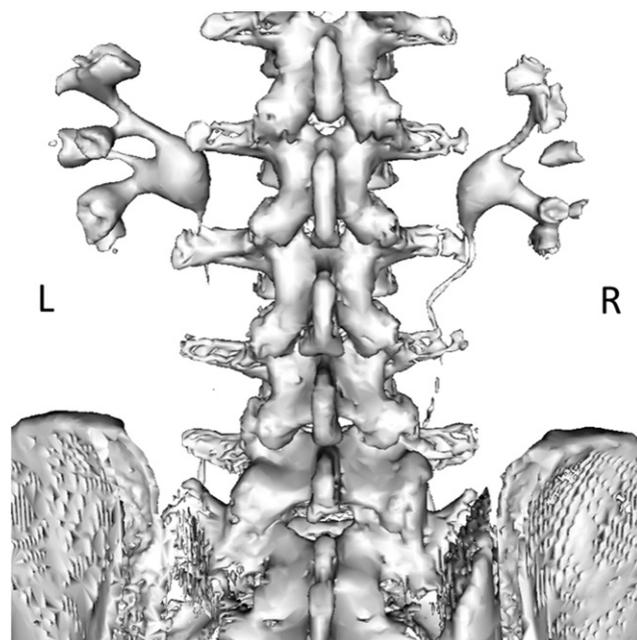
After segmentation and extraction, volumetric renderings of the collecting system and ureters were constructed using 3D-Doctor (Able Software, Lexington, Massachusetts). Surface renderings of the collecting system and bony anatomy were generated with OsiriX Imaging Software to serve as a reference for the anatomical axes of each patient (fig. 2).

### Image Analysis Determination of Primary Plane of Calyceal Groups

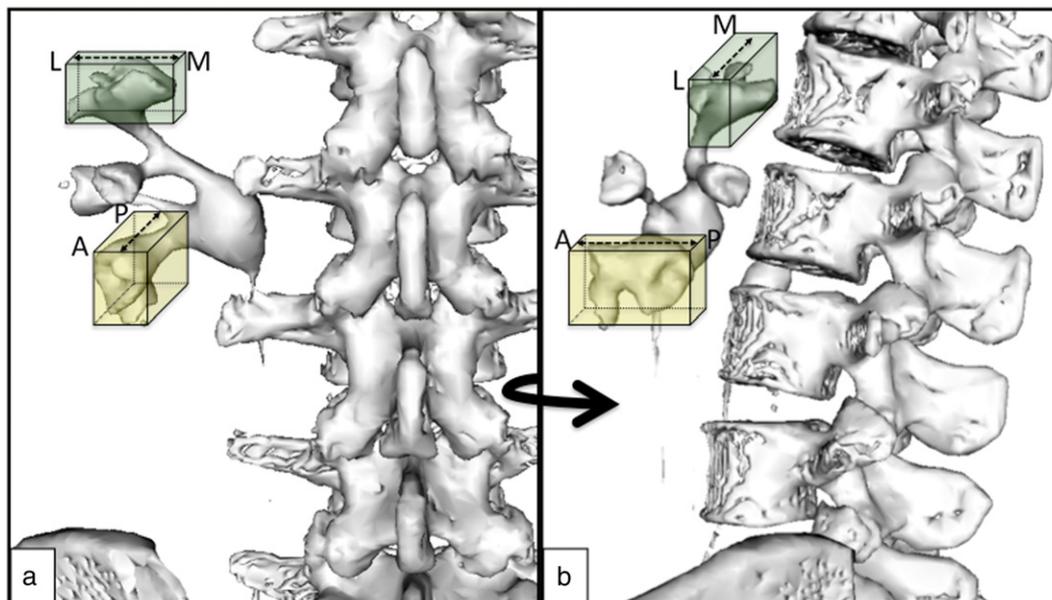
The primary plane of the upper, middle and lower pole calyceal group of each collecting system was determined by correlating axial CT imaging, volumetric renderings and surface renderings with the anatomical axes, as defined by the vertebral column and ribs. The primary plane was characterized as AP, ML or a combination of AP and ML (fig. 3).

### Simulation of Intraoperative Retrograde Pyelography and Lower Pole Target Calyceal Selection

A coronal MIP of each kidney was constructed to simulate fluoroscopic retrograde pyelography used during routine prone percutaneous access (fig. 4). The individual calyces of the lower pole calyceal group were designated calyces 1, 2 and 3 according to their location relative to the vertical



**Figure 2.** Surface rendering shows renal collecting system and bony anatomy. *L*, left. *R*, right.



**Figure 3.** *a* and *b*, 3D surface renderings show primary plane determination of calyceal groups. Green box indicates upper pole calyceal group with ML primary plane (dotted line). Yellow box indicates lower pole calyceal group with AP primary plane (dotted line). *L*, lateral. *M*, medial. *A*, anterior. *P*, posterior.

axis (fig. 5, *a*). The most inferior calyx was designated calyx 1. Moving superiorly, the subsequent calyces were designated calyx 2 and, when present, calyx 3. Based on MIP alone, an experienced urologist assessed the orientation of the calyces of the lower pole calyceal group and selected an individual calyx of the lower pole calyceal group as the proposed target for simulated percutaneous access, as in the setting of traditional prone PNL (fig. 5, *a*). The experienced urologist was not involved in the selection of images or the process of constructing MIPs. In effect, the urologist was blinded to the true 3D anatomy.

The selected individual calyx was documented. The 3D surface rendered model was rotated 90 degrees to the

sagittal view to determine whether the calyx would be appropriate for traditional prone PNL (fig. 5, *b*). We assessed the primary plane of the calyceal group and the orientation of the selected calyx. Calyceal orientations that were neutral or posterior and in the primary plane of the calyceal group were deemed appropriate for the maneuverability of rigid instrumentation. Anteriorly oriented calyces were deemed inappropriate. The orientation of other calyces in the lower pole calyceal groups was determined by the relationship of the long axis of the calyx to the anatomical axes of the patient.

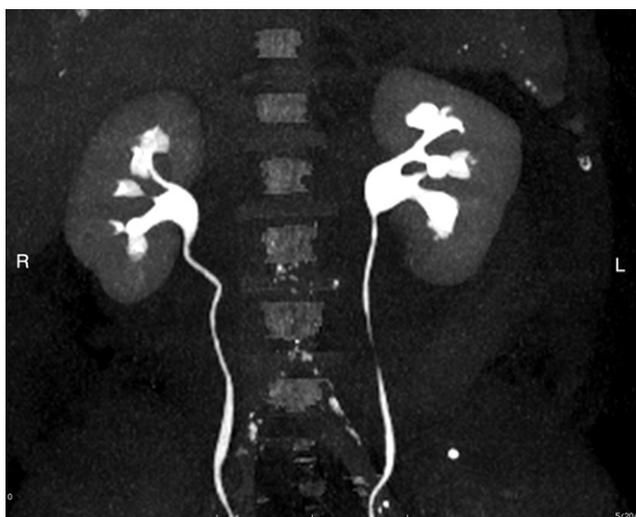
All data were recorded and analyzed using Excel®.

## RESULTS

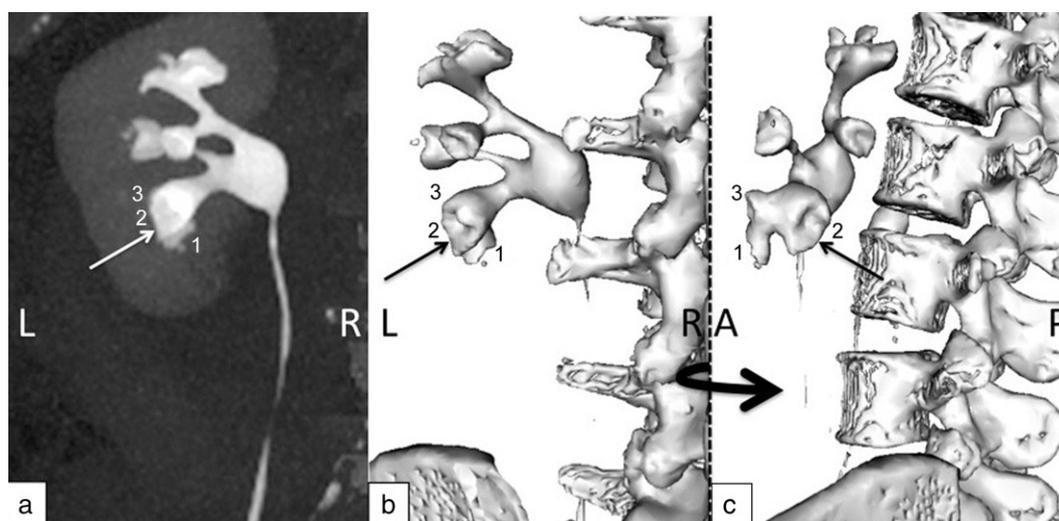
After excluding 20 studies with imaging artifacts or anatomical distortions, the images of 100 kidneys were suitable for processing, including 51 left and 49 right kidneys. The classic configuration of the upper, middle and lower pole calyceal groups was present in 98 kidneys. The collecting systems of 2 kidneys were bifid and lacked a distinct middle calyceal group.

### Primary Plane of Calyceal Groups

The primary plane of the upper pole calyceal group was ML in 95% of kidneys and a combination of AP and ML in 5%. The middle calyceal group had a primary plane of AP in 100% of kidneys. The primary plane of the lower pole calyceal group was AP in 95% of kidneys, ML in 3% and a combination of AP and ML in 2%.



**Figure 4.** Coronal MIP. *L*, left. *R*, right.



**Figure 5.** *a* to *c*, selection of calyx 2 (2) as proposed target (arrow) for simulated percutaneous access, as in setting of traditional prone PNL. 3, calyx 3. 1, calyx 1. L, left. R, right. A, anterior. P, posterior.

### Simulated Calyceal Selection for Lower Pole Percutaneous Access

Of 100 MIP images 97 were of sufficient quality to simulate fluoroscopic retrograde pyelography. In 90 of 97 simulations (93%) calyx 2 was selected as the proposed target for lower pole percutaneous access. Calyx 3 was selected in 7 of simulations (7%) but calyx 1 was not selected in any simulation.

After documenting the selected calyx, rotation of the 3D surface rendering revealed that the calyx selected was appropriate in 83 of 90 simulations (92%) in which calyx 2 was the target. In 7 simulations calyx 2 was the proposed target but the calyx was anteriorly oriented and inappropriate. In the 7 simulations in which calyx 3 was chosen as the target, 4 were appropriate and 3 were anteriorly oriented and inappropriate.

### Orientation of Individual Lower Pole Calyces

Calyx 1 was oriented anteriorly in 73 of 97 kidneys (75%) (see table). Calyx 2 was oriented posteriorly or was neutral to the primary plane of the lower pole calyceal group in 89 of 97 kidneys (92%). When assessed, calyx 3 was posteriorly oriented in 6 of 10 kidneys (60%).

#### *Orientation of calyces in lower pole calyceal group*

	No. Calyx 1 (%)	No. Calyx 2 (%)	No. Calyx 3 (%)
Anterior	73 (75)	7 (7)	3 (30)
Posterior	11 (11)	80 (82)	6 (60)
Neutral	11 (11)	9 (9)	1 (10)
Equivocal	2 (2)	1 (1)	—

### DISCUSSION

In 1941 Rupel and Brown first reported PNL.<sup>3</sup> Case reports and small series were subsequently reported until the technique gained popularity in the 1980s.<sup>4,5</sup> The evolution of endourological equipment and the adaptation of the angioplasty balloon for PNL tract dilation were instrumental to the widespread use of PNL.<sup>6</sup> From 1988 to 2002 the annual use of PNL in the United States more than doubled from 1.2/100,000 to 2.5/100,000 residents.<sup>7</sup>

As the procedure gained acceptance, interventional radiologists commonly acquired percutaneous renal access for PNL at a separate procedure. An early series of 522 cases of single setting, urologist acquired renal access and PNL showed that the rates of access success, complications and stone-free status were similar to those of radiologist acquired access.<sup>8</sup> Modern series confirmed these data and showed a significantly greater overall stone-free rate in cases of urologist acquired access.<sup>9</sup>

Despite the documented safety and efficacy of urologist acquired percutaneous renal access, as few as 11% of urologists who perform PNL achieve access.<sup>10</sup> Practical factors, such as equipment and facility availability, local practice patterns and privileging, may dictate whether a urologist or a radiologist obtains access for PNL. A perceived lack of skill is also among the most common reasons given by urologists for not achieving percutaneous renal access.<sup>11</sup> Implicit in this self-assessed lack of skill is the difficulty inherent in translating the 2-dimensional images of intraoperative fluoroscopy into the 3D anatomy of the renal collecting system. This challenging portion of the procedure is hindered by

the available anatomical references, which are contradictory, confusing and incomplete.

In 1901 Brödel provided detailed medical illustrations based on corrosion casts of 70 cadaveric kidneys.<sup>1</sup> He depicted the anterior calyces as medial and the posterior calyces as lateral. These findings became the main anatomical reference for open nephrolithotomy and for obtaining percutaneous access for endourological procedures.<sup>12</sup> Hodson sectioned cadaveric kidneys and contended precisely the opposite, that is the anterior calyces are located lateral and the posterior calyces are located medial ("lateral anterior, medial posterior").<sup>13</sup> Kaye and Reinke used data from early generation axial CT images to measure calyceal angles.<sup>2</sup> They concluded that the right kidneys were as described by Brödel<sup>1</sup> but for most left kidneys the description by Hodson was accurate.<sup>13</sup> A more contemporary version of the Brödel study<sup>1</sup> documented such wide variation in calyceal orientation that the investigators concluded that in most kidneys the calyces were alternately distributed and calyceal orientation was region dependent.<sup>14</sup>

The conclusions of many of these prior studies were based on ex vivo corrosion casts or single plane measurements from CT imaging, making the translation of the results into clinically useful information challenging. Moreover, an emphasis on the determination of the orientation of individual calyces overlooks the importance of the primary plane of the calyceal group. The calyceal group must be entered at an angle that permits the maneuverability of rigid instrumentation into the remaining renal collecting system. In the current study we examined in vivo 3D CT renderings, determined the primary plane of the calyceal groups and the orientation of individual calyces of the lower pole and applied our findings to simulated lower pole percutaneous renal access.

Upper pole renal access is desirable for treating isolated stones in the upper pole calyces and stones in the renal pelvis, lower pole calyces and ureter.<sup>15</sup> In 95% of the kidneys in our study the primary plane of the upper pole calyceal group was ML and generally neutral relative to the anteroposterior axis of the kidney. This suggests that upper pole renal access via any calyx would provide a working tract that parallels the long axis of the kidney or result in a working tract angle that would allow the maneuverability of rigid instrumentation to treat stones in the rest of the kidney.

Lower pole renal access is commonly used to treat lower pole stones. When accomplished via a posteriorly oriented or neutral calyx, lower pole access allows the instrument maneuverability necessary to treat stones in the remainder of the kidney. In our study the primary plane of 95% of lower pole calyceal groups was AP. This primary AP plane neces-

sitates selection of an appropriately oriented lower pole calyx to ensure adequate rigid instrument maneuverability. Inadvertent lower pole renal access via an anteriorly oriented calyx can result in an angle to the primary plane of the lower pole calyceal group that severely limits the movement of rigid instruments. A secondary renal access site or a secondary procedure may be required to treat stones in the remainder of the collecting system or proximal ureter. The results of our simulated target calyceal selection suggest that calyx 2 is oriented posteriorly in 92% of kidneys and should be the default calyx. Notably, calyx 1 is oriented anteriorly 72% of the time.

Several techniques can be used to assist the surgeon in interpreting the fluoroscopic imaging obtained intraoperatively during PNL, including the injection of air into the collecting system and dynamic rotation of the C-arm. The detailed calyceal anatomy that we obtained from 3D imaging highlights the importance of the orientation of the primary plane of the calyceal groups (upper pole mediolateral and lower pole anteroposterior) and serves to aid the surgeon in interpreting these dynamic images.

This study was retrospective and limited to the images of 100 kidneys. Approximately 20% of kidneys were excluded due to anatomical distortion or insufficient image quality. All images used to construct renderings were acquired with the patient supine. However, the mean difference in the axis of the kidney between the prone and supine positions is only 6 degrees.<sup>16,17</sup> Lastly, while this study stresses the importance of renal collecting system anatomy in the safe performance of PNL, the relative location of adjacent anatomical structures, such as ribs and pleura, and stone characteristics, including size, number and location, must also be considered.

## CONCLUSIONS

Selecting an appropriate calyx is critical to the safe, effective performance of PNL. The most important aspects of calyceal selection are the primary plane of the calyceal group and the orientation of the individual calyx.

Findings from our in vivo 3D CT renderings can be used to aid in interpreting intraoperative fluoroscopy, as demonstrated by our simulated lower pole calyceal selection. We believe that appropriate lower pole access can be reliably accomplished with an understanding of the typical anatomical relationships between individual calyceal orientation and the primary plane of the calyceal group. In the majority of cases the primary plane of the lower pole calyceal group is AP and the second calyx (calyx 2) is oriented posterior. Access via calyx 2 will facilitate rigid instrument insertion in the remaining calyces, renal pelvis and upper ureter for safe, effective PNL performance.

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## EDITORIAL COMMENT

The authors present an elaborate mapping of calyceal anatomy as it applies to percutaneous surgery, namely PNL. They identified relationships that have long been believed but never proven. They also challenge or redefine the long taught concept of lateral anterior, medial posterior. Because the upper pole calyceal group is oriented mediolateral, this may be the easier or more appropriate target, when feasible. When approaching with a lower pole puncture, the posterior calyx should be targeted to avoid a higher complication rate. Of approximately 1,000 urologist directed PNLs at our institution we tar-

geted the upper pole in about 75%. While this may sound aggressive, these authors have now objectified this approach as perhaps being sound and rational. The only suggestion that I have that would strengthen this study would be to compare their results to those in a cohort of patients with stones, ie patients undergoing PNL, to see whether their data are relevant.

**Brad Schwartz**

*Urology*

*Southern Illinois University School of Medicine  
Springfield, Illinois*

## REPLY BY AUTHORS

The comment highlights the clinical usefulness of our characterization of renal calyceal anatomy using state-of-the-art image processing techniques. The mediolateral orientation of the primary plane of the upper pole calyceal group provides a working tract angle that readily permits access to stones in the remainder of the collecting system. Therefore, upper pole access is appropriate in many of our patients as well, particularly when other factors are considered, such as stone burden and location. In contrast to the upper pole, the primary plane of the lower pole is anteroposterior in 95% of cases.

Thus, selecting a posteriorly oriented lower pole calyx is critical to assure the adequate maneuverability of rigid instrumentation. The radiographic simulation of percutaneous renal access in our study confirms the conclusions of Eisner et al in regard to the reliable posterior orientation of the second lower pole calyx.<sup>1</sup> Lastly, while we agree that examining a cohort of our patients undergoing PNL would strengthen our study, we believe that the clinical relevance of our findings is best demonstrated by its routine daily use in the operating room.

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