Abdominal Radiology

Published online: 8 September 2018

Abdom Radiol (2019) 44:612–618
https://doi.org/10.1007/s00261-018-1767-x

The anatomy of the renal pyelocaliceal system studied by CTU

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Abstract

Introduction and objectives: Knowledge of the pyelocaliceal system anatomy is essential for the safe and successful performance of endourologic procedures. The purpose of this study was to provide a better understanding of the full three-dimensional pyelocaliceal system anatomy.
Methods: Morphometric parameters of the three-dimensional reconstructions of computed tomography intravenous urography scans (n = 25 scans) were analyzed. Both kidneys were divided into three equal-sized segments (US: upper segment, MS: mid segment, LS: lower segment). Infundibular length (IL), infundibular width (IW), the number of calyces, and the transverse orientation in hours of a clock of each calyx as well as the dimension of the pyelum were determined.
Results: The mean upper IL (n = 92) was longer than the middle (n = 154) and lower IL (n = 112) (30.6 ± 7.9 mm vs. 16.4 ± 7.7 mm vs. 16.0 ± 6.0 mm, respectively; P = < 0.0001). IW was significantly smaller in the MS [3.7 ± 1.9 mm], followed by the US [4.6 ± 1.9 mm], and the LS [4.9 ± 2.2] in the increasing order. No correlation was found between IL and IW (Pearson correlation coefficient = 0.1). The US calyces were predominantly orientated lateral (8-10 o'clock: 44.5%) and medial (2–4 o'clock: 30.5%), in the MS lateral (8–10 o'clock: 87.6%) and anterolateral in the LS (9–12 o'clock: 67.9%). 74% of the kidneys consisted of 6–8 calyces (mean 7.2 ± 1.4, range 4–10), with the majority of the calyces in the MS (3.1 ± 0.8) followed by the LS (2.24 ± 0.8), and US (1.8 ± 0.7). There were no statistical differences between the right and left kidneys in terms of IL (P = 0.112) and number of calyces (P = 0.685).
Conclusion: Anatomic differences between the three segments of the pyelocaliceal system in terms of IL, IW, calyces number, and orientation are seen and should be considered when performing an endourologic procedure.

Key words: Renal anatomy—Pyelocaliceal system—Computed tomography

Urolithiasis is considered to be an important medical problem with an increasing prevalence and incidence in the past years [1]. It affects the functioning of individuals on different levels. Optimization of treatment will benefit the quality of life and the economic impact of the disease. The exact mechanism of stone formation remains unclear, but it has been suggested that, besides metabolic/diet factors, pyelocaliceal anatomic properties may play an important role in the etiology [2, 3].

Endourologic procedures, more specifically percutaneous nephrolithotripsy (PCNL) and ureterorenoscopy (URS) are the two main treatment modalities for renal stones. PCNL is the treatment of choice for larger stones (> 20 mm in diameter) while URS is the primary treatment modality for smaller/multiple calculi spreading in the different parts of the kidney [4]. Preoperative knowledge of the pyelocaliceal anatomy is fundamental to perform an accurate and safe puncture of the calyx when PCNL needs to be performed [5]. Technical improvements of the instrument and its miniaturization have led to an increased use of URS for both renal and ureteral calculi [4]. Although, the flexibility of the URS and its imaging have been improved as well as the techniques used in PCNL, both modalities have their

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limitations. Intraoperative limitations are beside body habitus, stone size, composition and location, very often caused by the anatomy of the kidney [6, 7].

Knowledge of the pyelocaliceal anatomy is essential to make both procedures more reliable and to improve the success rate of stone access and clearance. Controversy still exists on the surgical anatomy of the pyelocaliceal system. The anatomy and presumed function of the kidney and pyelocalcieal system was first described in the early years of science by a Persian philosopher named Avicenna [8]. The technology of injecting liquid rubber into the pyelocaliceal system to create endocast reprints, is introduced in studying anatomy of different structures among which the kidney and its pyelocaliceal system in the 20th century. This technique was able to clarify the internal relationships between the injected cavities but neglected the external relationship to the rest of the body as required for the surgical purpose. It was also prone to errors due to the shrinkage of the rubber after hardening or expansion when creating a higher pressure while injecting [9].

Previous studies suggest that success of endourologic procedures in relationship to the anatomy is mainly limited to the lower pole [7, 10–13]. The anatomic parameters of most interest are the angle formed between the main lower infundibulum and the renal pelvis (the infundibulopelvic angle), pelvis surface area, infundibular width and infundibular length [6, 10–12, 14].

The fine knowledge of the anatomy remains the keystone of surgical procedures [15]. The main limitation of previous studies was its 2-dimensional character by performing anatomic measurements on intravenous urography (IVU) [6]. Computed Tomography Urography (CTU) on the contrary makes it possible to measure in three-dimensional reconstructions. CTU has proved to be a useful imaging modality to analyze the intrarenal anatomic properties [16, 17].

We analyzed 25 CTU images, and both kidneys were studied separately. Calyces were counted in the upper, middle, and lower segments of each kidney. Calyx lengths in relation to the renal pelvis and its infundibular width as well as their orientation in the transversal plane are studied, and measurements were saved in a database for analysis. With the data so obtained, we expect to demonstrate a relationship between anatomic findings and their possible impacts on the surgical procedure and outcome.

Methods

Study design and subjects

The database of the department of radiology of our hospital has been used, and CTU scans made between January 2015 and January 2017 have been assessed. The CTU scans without uropathology and complete imaging of both pyelocaliceal systems were selected for further analysis. IRB approval was obtained.

Image analysis

CTU scans were made using Siemens Somatom definition flash. Patients were given iv contrast fluid 10 min before scanning.

All measurements were performed on a 3-dimensional reconstruction, made by Multiplanar Reconstruction/Maximum Intensity Projection (MPR/MIP) functionality in PACS IntelliSpace version 4.4.516.0 (Fig. 1). Late-phase CTUs (+ 10 min), when the whole pyelocaliceal system was filled with contrast, were used for 3D reconstruction.

Each kidney was divided into three equal-sized segments. The right and left kidneys of the subjects were analyzed separately. Every calyx was given a letter according to the alphabet, starting from cranial to caudal segment and from dorsomedial to lateral to medioventral position. Of each calyx, the infundibular length (IL) and the corresponding infundibular width (IW) were measured according to the method described by Elbahnasy et al. [11]. IL was measured in the middle of the infundibulum in a straight line beginning at the transition from renal pelvis to infundibulum to the most distal point of the corresponding calyx. IW was measured at the narrowest point along the infundibular axis. The mediolateral, anteroposterior, and craniocaudal distances of the renal pelvis were determined.

Orientation of the calyces in the transversal plane were registered according to the analog hour positions, clockwise for the right kidney and anticlockwise for the left kidney. Renal hilum is known by the definition at the three o'clock position, with the 9, 12, and 6 o'clock positions, respectively, representing laterally, anteriorly, and posteriorly orientated calyces.

Statistical analysis

Data analysis was performed using the software SPSS 22.00 (SPSS Inc, Chicago, IL). Normally distributed date are expressed as means $\pm$ SD. Statistical significance between the segments was evaluated using the independent sample *T* Tests. *P* values of 0.05 or less were considered to indicate statistical significance for all the statistical tests.

Results

A total number of 25 patients (7 male and 18 female) were included. The mean age of our study population was 50.8 $\pm$ 12.4 years (range, 26–75). Indications for the CTU scan were analysis macro/microscopic hematuria ($n = 18$), (history of) bladder tumor ($n = 4$), and per-

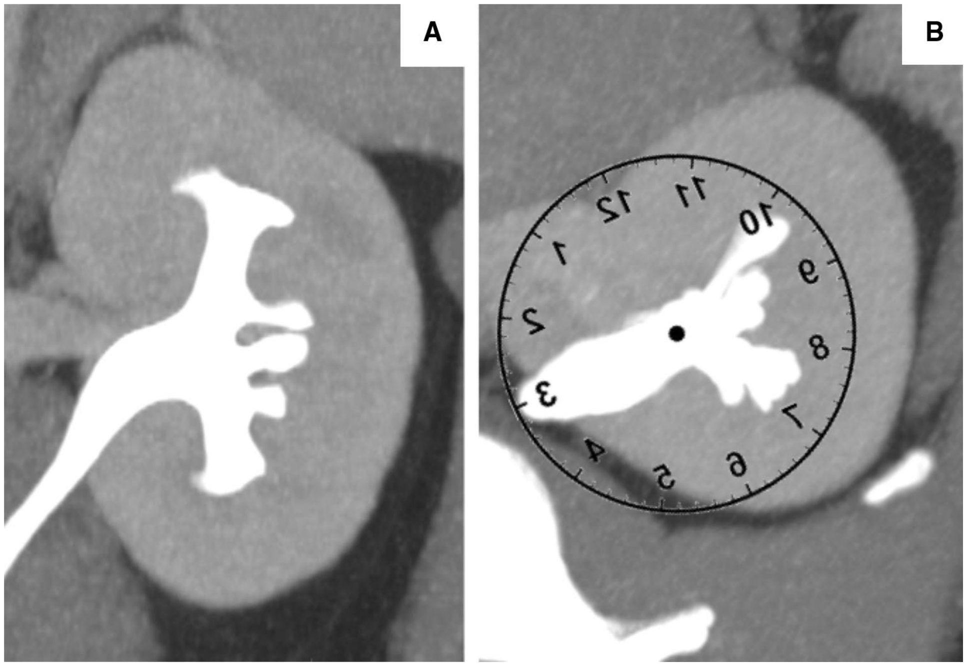

Fig. 1. 3-dimensional reconstruction of CTU scan. Coronal overview of pyelocaliceal system as generated during this study (Panel **A**); and transversal sectioning to study the orientation of the calyces (Panel **B**).

sisting flank pain ($n = 3$). The subjects had no history of surgery in the pyelocaliceal system.

Infundibular length (IL)

The mean upper IL ($n = 92$) was calculated to be 30.6 ± 7.9 mm, while the middle ($n = 154$) and the lower IL ($n = 112$) were measured as 16.4 ± 7.7 mm and 16.0 ± 6.0 mm respectively. The differences between ILs were statistically significant when the upper compared with the middle and the lower segment ($P < 0.0001$) (Table 1). The mean IL in the left pyelocaliceal system was slightly larger than the right one (20.7 ± 9.8 vs. 19.1 ± 9.2 mm) ($P = 0.112$).

Infundibular width (IW)

The mean IW was established to be 4.6 ± 1.9 mm, 3.7 ± 1.9 mm, and 4.9 ± 2.2 in the upper, middle, and lower segment, respectively. The middle IW was significantly smaller than the upper ($P = 0.0002$) and lower ($P < 0.0001$) segment (Table 1). There was no correlation between the IL and IW (Pearson correlation coefficient = 0.1).

Orientation and the number of the calyces

Figure 2 shows the frequencies of the transverse orientation of the calyces per segment. In the upper segment ($n = 92$), the most common orientation was lateral at 8 o'clock (22.8%) and medial at 4 o'clock (19.6%). A posterior orientation at 5, 6, or 7 o'clock was the most frequent in the upper segment (4.3%, 8.7%, and 6.5%, respectively) in comparison to the other segments. The orientation of the calyces in the mid segment ($n = 154$) was mostly lateral at 8, 9, and 10 o'clock (26.6%, 26.6%, and 34.4%, respectively). The lower segment orientation ($n = 112$) was predominantly lateral at 8, 9, and 10 o'clock (67.8%) and anterior at 11, 12, and 1 o'clock (25.1%).

The mean number of calyces per kidney ($n = 50$) was 7.2 ± 1.4 (range 4–10), with 74% ($n = 12$) of the kidneys

Table 1. Comparison between the upper, middle and lower segment of the pyelocaliceal system

	Upper segment (A)	*P* value (A vs. B)	Middle segment (B)	*P* value (B vs. C)	Lower segment (C)	*P* value (A vs. C)
N	92		154		112	
IL (mm)	30.6 ± 7.9 (17.0–50.4)	< 0.0001	16.4 ± 7.7 (2.7–37.9)	0.687	16.0 ± 6.0 (3.2–29.5)	< 0.0001
IW (mm)	4.6 ± 1.9 (1.5–11.0)	0.0002	3.7 ± 1.9 (1.2–11.0)	< 0.0001	4.9 ± 2.2 (1.2–10.4)	0.283

Values in cells correspond to the mean ± standard deviation (range)
IL, infundibular length; *IW*, infundibular width

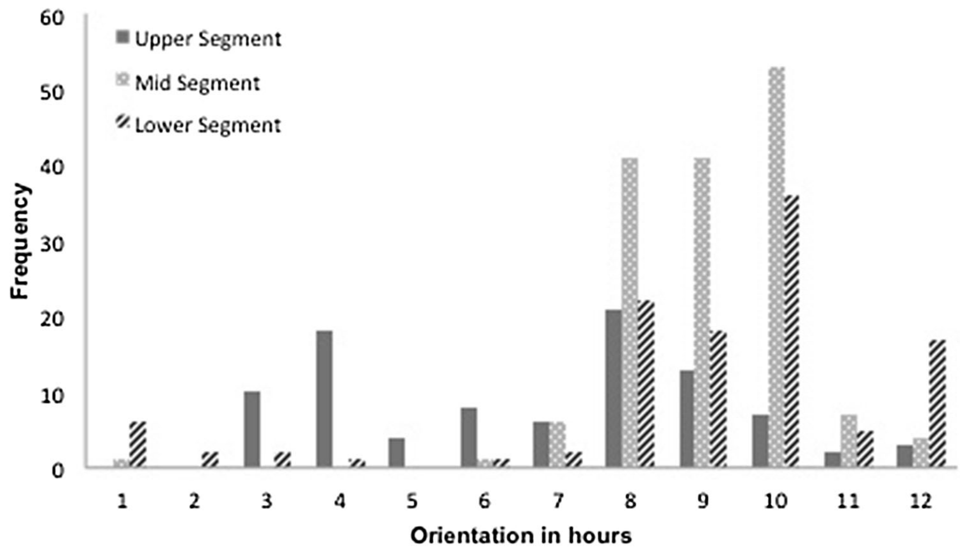

Fig. 2. Frequency of the transverse calyces orientation in hours per segment.

containing between 6 and 8 calyces. Divided into the upper, middle and lower segment the number of calyces were 1.8 ± 0.7, 3.1 ± 0.8, and 2.24 ± 0.8 respectively. These differences are all statistically significant as illustrated in Table 2. The US was drained by only 1 calyx in 30% of the cases and 18% in the LS, a single drainage of 1 calyx in the MS was not seen. No significant differences were found in the total number of calyces between ($P = 0.685$) the right and left kidney (Figs. 3, 4).

Morphometric properties of adult renal pelvis

The mean mediolateral dimensions of the renal pelvis were measured to be 19.9 ± 4.6 mm (range 10.6–29.2), while the craniocaudal and anteroposterior measured lengths were 16.6 ± 5.7 mm (range 7.1–34.7) and 11.2 ± 3.6 mm (range 5.5–18.7), respectively.

Discussion

This study describes the anatomic properties of the pyelocaliceal system and shows significant differences between the three segments of the kidney. MS calyces tends to have short and narrow infundibula, while the US calyces significantly have longer IL when comparing to the other segments. A lateral orientation of the calyces was most frequently found, with almost 90% of the ca-

Fig. 3. Measuring infunfibular width of the lower pole.

Table 2. Number of calyces in the upper, middle, and lower segment of the pyelocaliceal system

	Upper segment (A)	*P* value (A vs. B)	Middle segment (B)	*P* value (B vs. C)	Lower segment (C)	*P* value (A vs. C)
N	50		50		50	
Calyces	1.84 ± 0.65 (1–3)	< 0.0001	3.08 ± 0.83 (2–6)	0.0001	2.24 ± 0.85 (1–4)	0.009

Values in cells correspond to the mean ± standard deviation (range)

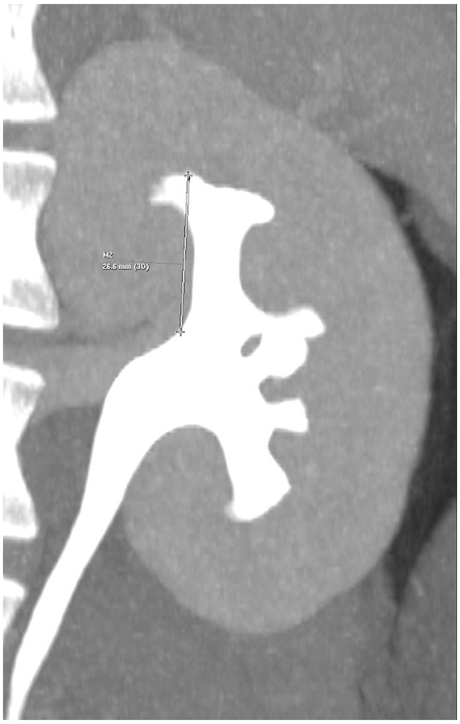

Fig. 4. Measuring infundibular length of the upper pole.

lyces in the MS. The US calyces were mainly orientated laterally and medially (75%) and anterolateral in the lower segment (67.9%).

The anatomy of the pyelocaliceal system

There are different approaches in the description of the anatomy of the kidney and the pyelocaliceal system in particular. Some describe the upper urinary tract (UUT) in relation to urine producing parenchyma, while others published the morphometric aspects of the cast made by polymers injection into the UUT [18]. Over the years different classifications of the pyelocaliceal system have been proposed. In 1998, Sampaio made a pyelocaliceal classification system using endocasts of the renal collecting system. Sampaio divided the endocasts into four morphological types, and the renal midzone drainage was decisive for this subdivision [18]. The majority of these studies described the 2D morphology of calyces using its length, diameter, and its angle of drainage into the pyelum in order to classify the anatomy into groups. In our opinion, the value of this classification is limited due to diversity of the morphology of the pyelocaliceal system.

There are different publications describing the lower pole anatomy in relation to the surgical outcomes. In 1992, Sampaio and Aragão [19] were the first authors, and later in 1998 Elbahnasy [11], to report that some lower pole anatomic features, such as an long IL (> 3 cm) [11] and a narrow IW (Sampaio: < 4 mm, Elbahnasy: < 5 mm), negatively affects the stone clearance after shock wave lithotripsies (SWL). In our study, infundibular length and width was measured according to the Elbahnasy method [11]. Our findings were considerably smaller than the mean IL and IW of the lower pole described by Elbahnasy himself. These differences may be due to different patient populations and/or different imaging of the pyelocaliceal system (IVP versus CTU).

We observed fewest numbers of calyces in the US with up to 30% being monocaliceal. Furthermore, US calyces are drained by a single midline infundibulum in 92% of the cases. In contrast, no fused single caliceal infundibulum was observed in the MS. Fused infundibula were only reported in 18% in the LS. The same findings were noted by Sampaio and Aragão who reported 98% and 42% single midline drainage of the superior and inferior pole respectively [20]. When approaching the pyelocaliceal system urologists should be aware of the differences in polar region drainage as multiple smaller infundibula would make it more difficult to remove renal stones.

The use of as well as the need for minimally invasive endourologic procedures like percutaneous nefrolithotripsy (PCNL) and flexible ureteroscopy (fURS) is growing. Instruments need to be increasingly more flexible, smaller sized and user-friendly for better handling by the urologist. Interventional radiologists need to access the optimal calyx considering the later planned PCNL when hydronephrosis due to the obstructing stone should be unburdened. Urologist needs to be informed of the 3D anatomy of the individual pyelocaliceal system in order to optimally navigate into the different calyces. In contrast to previous research, which was intensively focused on the anatomy of the lower pole and its prognostic values, we described the entire pyelocaliceal system. We provide a simple way of thinking and handling. One should be aware of the number of the calices, their locations and their orientation.

In our study, however, a mean lower segment IL of 16.0 ± 6.0 mm was reported which has a favorable outcome on the stone-free rate after both URS and SWL [10, 11]. Furthermore, we reported a mean IW of the lower segment of 4.9 ± 2.2 mm, which has a positive effect on the stone clearance after SWL [11]. Unfavorable outcomes, including a long mean IL of 30.6 ± 7.9 mm and a narrow mean IW of 3.7 ± 1.9 mm in the upper and mid segments, respectively, were also measured. Evidence in the literature on the impacts of the upper and mid segment renal anatomic properties on the success rate of endourologic interventions, however, is lacking.

PCNL/URS devices and procedures

Technical advances of endourological equipment over the years including improved deflection mechanism, superior (digital) imaging, and miniaturization of the device led to an increased use of both URS and PCNL [4]. Moreover, the new generation ureterorenoscopes show an increased success rate compared to their predecessors [21]. Where PCNL is concerned, technical evolutions have led to success rates that vary from 72% to 98% [6]. The anatomic architecture affects the results of the endourological procedure and hence needs to be clear preoperatively. Our results support the opinion that preplanning of URS and PCNL in order to decide for the puncture trajectory of PCNL and the route of (the difficult) URS is mandatory.

URS, despite the described technical evolution over the past years, also has its limitations. A long IL and an acute infundibulopelvic angle ($< 30°$) of the lower pole decrease the success rate [7, 14]. Jessen et al. reported a mean IL of the lower pole in the non-stone-free group of 28.3 mm which was significantly larger than the mean of the stone-free group (22.5 mm) [14]. Dorsal or ventral orientation of calyces, particularly in the LS makes it difficult to reach stones, also when using the newest generations of the flexible URS. This should be taken into account when studying the images of CTU.

Although less studied, the IL and IW seem not to negatively affect the success rate of PCNL. Only a large (> 20.5 cm^2) pelvis surface diminishes the success rate due to large area that may facilitate the escape of the stone to a not reachable place in the kidney [6].

Securing a proper percutaneous access of the pyelocaliceal system is the most crucial step in PCNL. Incidence of access related complications have been reported between 3% and 18% and include injury to adjacent organs, renal hemorrhage, failed access, and pneumothorax [22]. A proper preoperative analysis of imaging of the pyelocaliceal system is therefore mandatory. We perform PCNL in a hybrid operating theater to be able to access accurately. The target calyx for percutaneous puncture depends on the accessibility of a calyx, which is influenced by its orientation. Defining the orientation of each calyx has been found difficult by investigators and clinicians in 2D images. However, with the use of CTU volume-rendering technique, the calyx orientation becomes more reliable [23]. We have chosen to define the orientation of each calyx as clock hours, which are clear and easily reproducible parameters.

The literature suggests that a posterior calyx should be punctured since it has a low potential for bleeding complications [23]. A solely posterior orientation was rare in our study, and it was the most frequently found in the upper segment of the kidney. Besides a posterior orientation, we also preferred a more lateral orientation since these calyces are easily accessible. Puncturing a medial-orientated calyx in the upper pole is associated with significant risk of causing injury to the posterior segmental artery [23]. Care should be taken when the US is planned to puncture during the PCNL. We found a predominantly mediolateral orientation of the upper pole with almost 20% of the calyces medially orientated. These findings correlate with Miller et al. who found that the primary plane of the upper pole in 95% of the kidneys was mediolateral orientated [17].

Limitations of our study

This study was limited to the CTU volume renderings of 50 kidneys. Although we have been consistent in our measurement technique, one may debate about the tail ends of each measurement. Repeating the measurements by a second individual researcher minimized intraobserver variability.

We preferred to describe the orientation of the calyces according to a clock, since this is an easily reproducible method. The infundibulopelvic angle, a common measurement used in previous studies was avoided as there was a great intraobserver variation due to curved shape of the renal pelvis and the calyces.

Conclusion

This study comprehensively describes the anatomic properties of the pyelocaliceal system. It emphasizes the accessibility for percutaneous puncture of the MS and LS calyces. Care should be taken when US calyces are planned to be punctured for PCNL, since some are medially oriented and thus not accessibility oriented. Also, the narrowest infundibula were reported in the MS, which could make it less accessible for URS. For URS, dorsoventral orientation of some calyces makes it difficult to access. Preoperative imaging using CTU and knowledge of the individual anatomy is important when optimizing outcome of URS and PCNL.

Acknowledgements None.

Compliance with ethical standards

Disclosures or Funding None.

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