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Anatomical arrangement and variations of the renal pelvis- A cadaveric study with its surgical relevance

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Abstract

Background: The renal pelvis plays a pivotal role in urine drainage and maintains close anatomical relationships with the calyces and ureter. Variations in its anatomy are of significant clinical and surgical importance, particularly in renal and urological interventions. ***Aim:*** To study the anatomical arrangement and variations of the renal pelvis and evaluate their surgical relevance through cadaveric dissection. ***Materials and Methods:*** This descriptive cadaveric study was conducted on 80 kidneys obtained from formalin-fixed adult human cadavers in the Department of Anatomy of Government Medical College, Kozhikode. Detailed dissections were performed to study the renal pelvis, calyces and ureter. Morphological patterns, positional variations, and measurements were documented. Data were analyzed using descriptive statistics and appropriate tests of significance. ***Results:*** An intrarenal pelvis was observed in 56.7% of specimens, while 43.3% showed an extrarenal pelvis. Funnel-shaped pelvis and tri-calyceal patterns were the most common configurations. Variations in pelvi-ureteric junction orientation and calyceal arrangement were frequently encountered. A significant proportion of specimens demonstrated anatomical features associated with increased surgical complexity, risk of ureteropelvic junction obstruction, and difficulty in endourological access. ***Conclusion:*** The study demonstrates that anatomical variations of the renal pelvis are common and possess considerable surgical relevance. Awareness of these variations is essential for accurate preoperative assessment, safer surgical approaches, and improved outcomes in renal and urological procedures

Keywords: Renal pelvis. Pelvicalyceal system. Cadaveric study

INTRODUCTION

The renal pelvis is a funnel-shaped structure that forms the proximal part of the ureter and plays a crucial role in the collection and drainage of urine from the kidney. It is formed by the convergence of major calyces, which in turn receive urine from minor calyces. The anatomical arrangement of the renal pelvis, calyces, renal vessels, and ureter shows considerable variability among individuals. These variations are of immense clinical and surgical importance, particularly in urological and renal surgeries such as pyeloplasty, percutaneous nephrolithotomy, renal transplantation, and endourological procedures.[1]

Classically, the renal pelvis lies within the renal sinus and continues as the ureter at the pelvi-ureteric junction. However, variations such as intrarenal and extrarenal pelvis, differences in the number and arrangement of calyces, and altered relationships with renal arteries and veins are commonly encountered. An extrarenal pelvis, for instance, lies outside the renal sinus and is more distensible, which may predispose it to urinary stasis, infection, or misinterpretation as hydronephrosis on imaging. Similarly, variations in calyceal patterns—such as bi-calyceal or tri-calyceal systems—can influence surgical access and drainage procedures.[2]

The close anatomical relationship of the renal pelvis with segmental renal vessels adds another layer of surgical relevance. Aberrant or accessory renal arteries crossing anterior or posterior to the pelvis may lead to ureteropelvic junction obstruction or increase the risk of vascular injury during surgical interventions. A precise understanding of these anatomical relationships is therefore essential to minimize intraoperative complications, reduce operative time, and improve surgical outcomes.[3]

Cadaveric studies provide a reliable and direct method for understanding normal anatomy and its variations, free from the distortions caused by pathological conditions or imaging limitations. Such studies allow detailed visualization of structures and their spatial relationships, offering valuable insights for surgeons, anatomists, and radiologists alike. Despite advances in imaging techniques, cadaveric dissection remains the gold standard for studying anatomical variations.[4]

AIM

To study the anatomical variations of the renal pelvis and evaluate their surgical relevance through cadaveric dissection.

OBJECTIVES

1. To observe the anatomical arrangement of the renal pelvis, calyces and ureter in cadavers.
2. To identify and document variations in the morphology and position of the renal pelvis and calyceal system.
3. To assess the surgical relevance of these variations with respect to renal and urological procedures

MATERIALS AND METHODS

Source of Data

The study material consisted of kidneys obtained from formalin-fixed adult human cadavers available in the Department of Anatomy of Government Medical .College, Kozhikode

Study Design

.This was a descriptive cadaveric observational study

Study Location

The study was conducted in the Department of ..Anatomy, at Government Medical College, Kozhikode

Study Duration

.The study was carried out over a period of three year

Sample Size

A total of 80 kidneys (from both right and left sides) .were included in the study

Inclusion Criteria

- Adult cadavers of either sex
- Well-preserved kidneys without visible gross damage

Exclusion Criteria

- ,Cadavers with evidence of renal pathology, trauma or previous renal surgery
- Congenital anomalies grossly affecting the kidney

Procedure and Methodology

Kidney was exposed anteriorly through standard dissection. The renal capsule was removed, and the renal sinus was opened meticulously to visualize the renal pelvis, calyces and ureter. The position of the renal pelvis (intra-renal or extra-renal) and pattern of calyces were observed and recorded. Variations were noted and .photographed wherever necessary

Sample Processing

Dissected specimens were cleaned and preserved in formalin. Detailed anatomical findings were .documented using standardized proformas

Statistical Methods

Data were entered into Microsoft Excel and analyzed using descriptive statistics. Results were expressed as .frequencies and percentages

Data Collection

Observations were systematically recorded during dissection, including morphological patterns and anatomical relationships of the renal pelvis and .associated structures

RESULTS

Table 1: Anatomical Arrangement and Variations of Structures in the Renal Pelvis (N = 80)

Parameter	± Category / Mean SD	(%) n	CI %95	Test of Significance	p-value
Type of Renal Pelvis	Intrarenal	(56.25) 45	66.6–45.4	One-sample proportion test	**0.046**
	Extrarenal	(15.0) 12	24.8–8.0		
	Borderline	(28.75) 23	39.6–19.4		
Pelvis Shape	Funnel shaped	(62.5) 50	73.1–51.0	χ^2 goodness-of-fit	**0.022**
	Branched	(37.5) 30	49.0–26.9		
Length of Renal Pelvis (mm)	Mean ± SD	4.6 ± 27.8	28.8–26.8	One-sample t-test	**0.001>**
Pelvi-ureteric Junction Orientation	°70>	(72.5) 58	81.7–61.7	χ^2 test	**0.001>**
	°70<	(27.5) 22	38.3–18.3		

Table 1 illustrates the anatomical arrangement and variations of structures in the renal pelvis among 80 specimens. The most common type of renal pelvis observed was intrarenal, present in 45 cases (56.25%), followed by borderline type in cases (28.75%) and extrarenal type in 12 cases (15%). The distribution showed a statistically significant predominance 23 ,of the intrarenal type ($p = 0.046$). Regarding pelvic morphology, funnel-shaped pelvis was the most frequent configuration observed in 50 specimens (62.5%), while branched pelvis was noted in 30 specimens (37.5%), with the difference being statistically significant ($p = 0.022$). The mean length of the renal pelvis measured 27.8 ± 4.6 mm, and the one-sample t-test demonstrated that this value differed significantly from the reference anatomical average ($p < 0.001$), indicating notable morphological variation in the studied specimens. In terms of pelvi-ureteric junction orientation, the majority of .specimens (58 cases; 72.5%) showed an angle less than 70°, whereas 22 cases (27.5%) had an orientation greater than 70° .This distribution was highly significant (p < 0.001)

Table 2: Anatomical Arrangement of Renal Pelvis, Calyces, Ureter (N = 80)

Parameter	± Category / Mean SD	(%) n	CI %95	Test of Significance	p-value
Major Calyces Number	Two	(36.25) 29	47.8–25.8	χ² goodness-of-fit	**0.011**
	Three	(50.0) 40	61.4–38.6		
	Multi	(13.75) 11	23.2–7.1		
Minor Calyces (count)	Mean ± SD	1.8 ± 9.6	10.0–9.2	One-sample t-test	**0.001>**
Ureter Origin	Central	(77.5) 62	86.0–67.0	χ² test	**0.001>**
	Lateral	(22.5) 18	33.0–14.0		
Pelvic Duplication	Present	(%0) 0	4.5–0	Fisher's exact test	**0.001>**
	Absent	(%100) 80	100–95.5		

Table 2 presents the anatomical arrangement of renal pelvis structures, including calyces and ureteric origin. Among the specimens studied, three major calyces were the most common configuration, observed in 40 cases (50%), followed by 80 two calyces in 29 cases (36.25%) and multiple calyces in 11 cases (13.75%). The variation in the number of major calyces .was statistically significant (p = 0.011), indicating that the three-calyx pattern is the predominant anatomical arrangement > The mean number of minor calyces was 9.6 ± 1.8, which differed significantly from the expected anatomical average (p suggesting variability in calyceal branching patterns. Regarding the origin of the ureter, the majority of cases (62 ,(0.001 specimens; 77.5%) exhibited a central origin, whereas 18 specimens (22.5%) showed a lateral origin, and this distribution was highly significant (p < 0.001). Additionally, pelvic duplication was not observed in any specimen, with all 80 kidneys .showing a single renal pelvis, and Fisher's exact test confirmed this finding as statistically significant (p < 0.001) (%100)

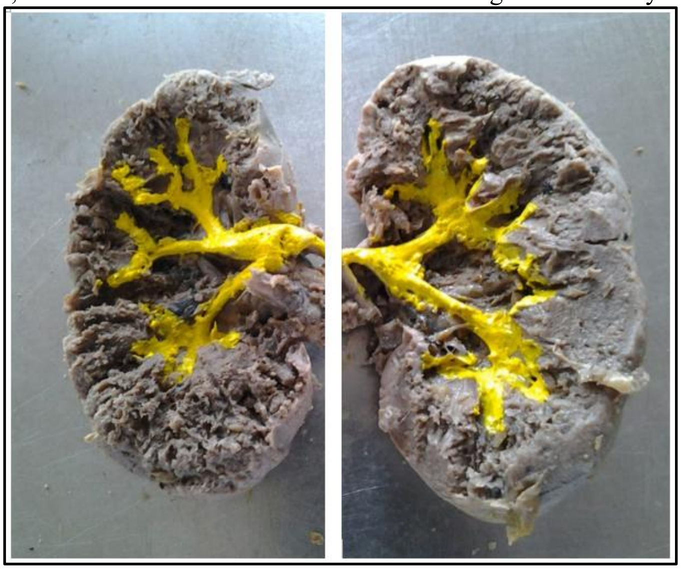

Figure 1 **Figure 2**

Figure 1. Gross anatomical section of kidney showing the renal pelvis and pelvicalyceal system, demonstrating the .branching pattern of major and minor calyces with intrarenal pelvis configuration

Figure 2. Longitudinal section of kidney specimen showing the renal pelvis and calyceal branches, illustrating the .arrangement of major calyces, minor calyces, and ureteric origin within the renal sinus

DISCUSSION

Anatomical arrangement and variations of the renal pelvis (Table 1)

The present study evaluated the anatomical arrangement and morphological variations of the renal pelvis in 80 specimens and demonstrated that the intrarenal pelvis was the most common type, observed in 56.25% of cases, followed by borderline pelvis in 28.75% and extrarenal pelvis in 15%. These findings are consistent with classical anatomical descriptions indicating that the intrarenal pelvis is the predominant configuration in the majority of individuals. Similar observations were reported by Sampaio et al. (2023)[1], who described the intrarenal pelvis as the most frequent pattern encountered during renal anatomical studies and emphasized its clinical importance in procedures such as percutaneous nephrolithotomy and endourological interventions. Likewise, Morais et al. (2024)[3] reported that intrarenal pelvis configuration predominates in most populations and significantly influences the drainage pattern of the pelvicalyceal system.

In the present study, funnel-shaped pelvis was the most common morphological type, observed in 62.5% of specimens, whereas branched pelvis was identified in 37.5% of cases. These results are comparable with the findings of Talyshinskii et al. (2025)[10], who reported that funnel-shaped pelves constitute the dominant morphological pattern of the renal collecting system, while branched types occur less frequently. Similarly, Chhabra et al. (2020)[5] reported that approximately 60–65% of kidneys show a funnel-shaped pelvis, which corresponds closely with the proportions observed in the present study.

The mean length of the renal pelvis in the current study was 27.8 ± 4.6 mm, indicating moderate morphometric variability among specimens. Comparable measurements were documented by Côrtes et al. (2025)[6], who reported an average renal pelvis length ranging between 25 and 30 mm based on advanced imaging and anatomical studies. In addition, Maurya et al. (2025)[8] noted similar morphometric values in Indian cadaveric studies and highlighted that renal pelvic length may vary according to anatomical configuration and associated vascular relationships.

Another important observation in the present study was the orientation of the pelvi-ureteric junction (PUJ). The majority of specimens (72.5%) demonstrated an angle less than 70°, whereas 27.5% showed orientation greater than 70°. These findings are supported by Chakravarthi et al. (2024)[2], who observed that most renal pelves demonstrate a relatively acute PUJ orientation, which facilitates efficient urine drainage into the ureter. Similarly, Dawani et al. (2021)[4] emphasized that the spatial orientation of the renal pelvis and ureter is influenced by developmental rotation of the kidney and may show moderate variations in cadaveric specimens.

Anatomical arrangement of calyces, ureter, and associated structures (Table 2)
The analysis of the pelvicalyceal system in Table 2 showed that the most common number of major calyces was three (50%), followed by two calyces (36.25%) and multiple calyces (13.75%). These findings correspond with previously reported anatomical patterns of the renal collecting system. Morais et al. (2024)[3] noted that most kidneys typically possess two or three major calyces, which subsequently divide into multiple minor calyces draining the renal papillae. Similarly, Talyshinskii et al. (2025)[10] reported that the tri-calyceal pattern is one of the most frequently observed configurations in the renal collecting system.

The mean number of minor calyces in the present study was 9.6 ± 1.8, indicating a relatively consistent branching pattern among the specimens examined. Comparable findings were reported by Sampaio et al. (2023)[1], who described that most kidneys contain 8–12 minor calyces, with variations depending on the anatomical arrangement of the renal pyramids. Walker et al. (2020)[11] also reported similar morphometric distributions of minor calyces during cadaveric anatomical studies.

With respect to the origin of the ureter, the current study demonstrated that the ureter arose centrally in 77.5% of specimens and laterally in 22.5%. These findings are consistent with those reported by Dawani et al. (2021)[4], who observed that the ureter most commonly arises centrally from the renal pelvis, while lateral origin represents a less frequent anatomical variation. Likewise, Jyothi et al. (2025)[9] reported that the relationship between renal vessels and ureteric origin varies depending on the branching pattern of renal vessels and the development of the renal hilum.

Interestingly, pelvic duplication was not observed in any specimen (0%) in the present study. Although duplication of the renal pelvis is a known congenital anomaly, it is relatively uncommon. Chakravarthi et al. (2024)[2] reported that duplicated renal pelvis or ureter occurs in a small percentage of individuals and is often associated with accessory renal arteries or developmental anomalies. Similarly, Poudiougo et al. (2023)[12] described rare cases of renal pelvic duplication associated with ectopic kidneys and vascular anomalies.

The present study demonstrates that while the renal pelvis and pelvicalyceal system exhibit several anatomical variations, the majority of kidneys follow the classical anatomical pattern described in standard anatomical literature. Understanding these variations is clinically important for renal surgery, endourological procedures, and radiological interpretation, as highlighted by several recent anatomical and imaging studies (Sampaio et al., 2023[1]; Morais et al., 2024[3]; Côrtes et al., 2025[6]).

CONCLUSION

The present anatomical study evaluated the arrangement and variations of the renal pelvis, calyceal system, and ureteric origin in a sample of 80 specimens, providing valuable insights into the morphology of the renal collecting system. The findings demonstrated that the intrarenal type of renal pelvis was the most common anatomical configuration, observed in more than half of the specimens. This predominance supports classical anatomical descriptions and emphasizes that intrarenal pelvis arrangement represents the typical structural pattern in the majority of individuals. The presence of extrarenal and borderline pelvis types in a smaller proportion of cases highlights the natural variability in renal pelvic morphology, which is clinically relevant .during radiological interpretation and surgical planning

The study also revealed that funnel-shaped pelvis was the most frequently encountered morphological pattern, followed by branched pelvis. Funnel-shaped configurations are considered functionally efficient for urine drainage and are commonly described in anatomical and radiological literature. The average length of the renal pelvis was found to be 27.8 ± 4.6 mm, indicating moderate morphometric variability among specimens. Such morphometric data are important for understanding the spatial relationships within the renal hilum and for planning procedures such as endourological interventions, percutaneous nephrolithotomy, and reconstructive renal surgery.

Another important observation was the orientation of the pelvi-ureteric junction, where the majority of specimens demonstrated an angle less than 70 degrees. This anatomical orientation facilitates smooth urine flow from the renal pelvis into the ureter and plays a crucial role in maintaining normal urinary drainage. Variations in this angle may predispose individuals to conditions such as pelvi-ureteric junction obstruction, making knowledge of these variations clinically significant.

The analysis of the pelvicalyceal system showed that three major calyces were the most common arrangement, followed by two calyces and multiple calyces. Additionally, the mean number of minor calyces was 9.6 ± 1.8, which corresponds with the classical anatomical description of renal papillary drainage patterns. The ureter was found to originate centrally in the majority of specimens, while lateral origin represented a less frequent variation. Importantly, no cases of pelvic duplication were identified in the present study, suggesting that congenital duplication anomalies are relatively rare in the studied population.

LIMITATIONS OF THE STUDY

1. **Limited sample size:** The study was conducted on a relatively small sample of 80 specimens, which may not fully represent the entire population variability in renal pelvic anatomy.
2. **Single-center study:** The specimens were obtained from a single institution, which may limit the generalizability of the findings to broader populations or different ethnic groups.
3. **Cadaveric nature of the study:** Since the study was performed on cadaveric specimens, physiological factors such as renal perfusion, dynamic urinary flow, and functional relationships could not be assessed.
4. **Lack of demographic data:** Information regarding the age, sex, and clinical history of the specimens was not available in all cases, which prevented correlation of anatomical variations with demographic factors.
5. **Absence of radiological correlation:** The study relied primarily on direct anatomical observation and measurements without comparison with imaging modalities such as CT urography or MRI, which could provide additional functional and structural insights.
6. **Limited evaluation of vascular relations:** Although the study focused on renal pelvis and pelvicalyceal anatomy, detailed assessment of associated renal vascular variations was not performed.
7. **Cross-sectional observational design:** The descriptive nature of the study limits the ability to establish causal relationships or developmental mechanisms responsible for the observed variations.
8. **Possible measurement bias:** Minor errors in morphometric measurements could occur due to manual measurement techniques used during specimen analysis.
9. **Rare anomalies may not be detected:** Because of the limited number of specimens, uncommon anomalies such as duplicated pelvis or complex congenital variations might not have been observed.
10. **Lack of clinical outcome correlation:** The study did not correlate anatomical variations with clinical conditions such as ureteropelvic junction obstruction, nephrolithiasis, or surgical outcomes, which could further enhance clinical relevance.

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