Original Article

Modified Takazawa anatomical classification of renal pelvicalyceal system based on three-dimensional virtual reconstruction models

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Background: Previous classification of renal pelvicalyceal anatomical structure may be difficult to intuitively understand and unpractical for endourological surgery. We aim to put forward a modified Takazawa anatomical classification of renal pelvicalyceal system based on three-dimensional (3D) virtual reconstruction models for endourological surgery.

Methods: We retrospectively collected data on 225 patients (320 kidneys) in total between Apr. 2017 and Dec. 2020, spatial anatomical structure of renal pelvis and calyces were modeled and corresponding morphological parameters were measured after 3D virtual reconstruction of computed tomography urography (CTU). The modified Takazawa renal pelvicalyceal anatomical classification was advanced based on the renal pelvicalyceal morphological parameters [bifurcated branches of renal pelvis, cross sectional area of renal pelvis and ureteropelvic junction (UPJ), infundibuloureteral angle (IUA), lower pole infundibular calyceal length (IL)] by 3D virtual reconstruction models, and comparison of renal pelvicalyceal system morphological parameters were performed to evaluate the differences in various classification types of renal pelvis and calyces.

Results: Anatomical structure of renal pelvis and calyces were divided into two main types (Type A and Type B) according to renal pelvic branch patterns. A single pelvis without bifurcated branch was regarded as Type A (62%) and subclassified into three subtypes: Type A1 (22%), Type A2 (27%) and Type A3 (13%), the slimline pelvis was classified as Type A1, the typical pelvis as Type A2 and the broad pelvis as Type A3. A divided pelvis with bifurcated branches was seen as Type B (38%) and subclassified into two subtypes: Type B1 (15%) with the wide and flat lower calyx branch, Type B2 (23%) with the narrow and steep lower calyx branch.

Conclusions: Previous studies have reported that the visualization and classification of renal pelvicalyceal anatomical structure by endocast, autopsy, ultrasonography and excretory urography, the modified Takazawa classification system based on 3D virtual reconstruction models enables to standardized different anatomical morphology of renal pelvicalyceal system and provide intuitive and concise information on anatomy, thus leading to the improvement in treatment modality.

Keywords: Renal pelvicalyceal system; renal anatomy classification; three-dimensional virtual reconstruction; urolithiasis; endourology

Introduction

In recent years, advances in endourology, interventional radiology and percutaneous nephrolithotomy (PCNL) have rekindled interest in the anatomy of renal pelvicalyceal system (1,2), as a comprehensive understanding of such anatomy is essential to achieve reliable endourologic surgery using for the treatment of urolithiasis, upper urinary tract urothelial tumors and chronic unilateral hematuria (3-6).

When we analyze the structure of kidney, we observe that the pelvis and calyces are the most varied in number, position and shape. Renal pelvicalyceal anatomy may play a role in the selecting the best endourologic treatment for a particular patient. It is necessary to fully understand the three-dimensional (3D) renal pelvicalyceal anatomical structure, in order to interpret the preoperative images accurately and complete the operation effectively and safely.

Brödel reported the anatomy of the renal pelvis and vessels in 1901 and he divided the renal pelvis into two types: the true pelvis and the divided pelvis (7), some following renal pelvicalyceal classifications have been proposed progressively. However, we think that several important details of pelvicalyceal anatomy still have not been discussed, these classifications do not assist clinical endourologic applications and the morphologic types they grouped deserve to be described thoroughly. To visualize the renal pelvicalyceal system in three dimensions and help urologists to image the characteristic of the renal calyces for a better chose of therapeutic option, we systematically studied the 3D virtual reconstruction models of the renal pelvis and calyces and put forward modified Takazawa kidney collecting system morphologic classification of clinical value to endourologists. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/tau-21-309).

Methods

Study object

We retrospectively collected data on a total of 320 renal pelvicalyceal systems from computed tomography urography (CTU) of 225 patients, who underwent urological imaging examinations due to malignant or benign disease of urinary system at our hospital during the period from Apr. 2017 to Dec. 2020. 3D virtual reconstruction models of hydronephrosis, urinary tract malformation, or poor image quality were excluded. All procedures performed in this study were in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the Ethics Committee of Peking University First Hospital (approval number: 2020-346). Because of the retrospective nature of the research, the requirement for informed consent was waived.

CT scan and 3D virtual reconstruction models

Enhanced CT scans were completed in all patients using a 64-slice CT system with 0.625 mm slice thickness (Light-Speed VCT, GE Healthcare, USA), the original CT data for the following analysis were set to the image quality and stored in DICOM (Digital Imaging and Communications in Medicine) format. Different phase CT data were segmented and reconstructed to create 3D digital images through Medical Imaging Three Divisional Visualization System (Yorktal, Inc., Shenzhen, Guangdong, China). The threshold value method was used to extract a targeted region. 3D virtual reconstruction models of the renal pelvicalyceal system were obtained based on secretive phase data, while other retroperitoneal anatomical structures including renal parenchyma, renal artery, vein, abdominal aorta and inferior vena cava were reconstructed simultaneously using the region-growing method based on arterial and parenchymal phase data (8).

Data collection and statistics analysis

We measured characteristics of the renal pelvicalyceal system, including side of kidney collecting system, number of renal calyces, cross-sectional area of renal pelvis, angle between the central axis of renal pelvis and upper ureter, infundibulopelvic angle (IPA), infundibuloureteral angle (IUA) and infundibular calyceal length (IL). We then put forward the modified Takazawa anatomical classification based on the renal pelvicalyceal morphological parameters mentioned above and compared the difference of the renal pelvicalyceal types. The angle was measured as described by Elbahnasy *et al.* (9). And in our study, the cut-off value of

Table 1 Morphological parameters of all modified Takazawa renal pelvicalyceal classification types

Variable	Value
Number of patients, n	225
Number of renal pelvicalyceal system, n	320
Side of renal pelvicalyceal system, n [%]	
Left	154 [48]
Side	166 [52]
Number of major renal calyces, n	2.59±0.65 [2.00–3.00]
Number of minor renal calyces, n	8.35±2.75 [7.00–9.00]
Cross-sectional area of UPJ, mm^2	14.99±14.42 [5.40–18.98]
Cross-sectional area of renal pelvis in single pelvis, mm^2	83.47±56.83 [41.23–111.62]
Cross-sectional area of upper bifurcated branches in divided pelvis, mm^2	13.66±11.47 [5.61–19.86]
Cross-sectional area of lower bifurcated branches in divided pelvis, mm^2	26.87±22.86 [10.26–36.41]
Angle between the central axis of renal pelvis and upper ureter	134.16±14.16 [125.73–143.23]
Infundibulopelvic angle (IPA)	87.81±17.68 [77.27–97.62]
Infundibuloureteral angle (IUA)	42.84±20.78 [28.28–55.85]
Lower pole infundibular calyceal length (IL), mm	30.21±11.70 [21.43–37.71]
Cross-sectional area of Infundibulum section of inferior calyx, mm^2	16.08±14.98 [5.05–21.40]

Data are presented in terms of mean ± standard deviation [inter quartile range] or the numbers of individuals. UPJ, ureteropelvic junction.

classification and sub-classification was based on previous literature and our data distribution.

Statistical analyses were conducted by means of SPSS version 22.0 software (SPSS, Inc., IBM Corp., Somers, NY). Mean and median were calculated for descriptive purposes. Although we are consistent in measurement technique, people may argue about the end of each measurement. The measurement repeated by a second experienced individual researcher could minimize intra-observer variability.

Results

Of the 320 renal pelvicalyceal system from 225 patients were included as study subjects and analyzed, according to inclusion and exclusion criteria (*Table 1*). Anatomical structure of renal pelvis and calyces were divided into two major types (Type A and Type B) according to the renal pelvic branch patterns (*Figure 1*). Type A (198/320, 62%) was present a single pelvis without bifurcated branch and subclassified into three subtypes according to the cross-sectional area of renal pelvis (*Figure 2A*): Type A1 (70/320, 22%), Type A2 (86/320, 27%) and Type A3 (42/320, 13%).

If the cross-sectional area ratio of the pelvis to the UPJ was less than 4 times, the pelvis was considered to be type A1, which was a slimline pelvis morphology. The type A2 formed a typical funnel shaped pelvis and the cross-sectional area of the pelvis was about 4–16 times larger than that of the UPJ, and this subtype was the most frequently observed standard morphology. The type A3 subtype was a broad pelvis morphology which formed a large box shaped pelvis with the cross-sectional area ratio of the pelvis to the UPJ greater than 16 times.

A divided pelvis with bifurcated branches was seen as Type B (122/320, 38%) and subclassified into two subtypes: Type B1 (48/320, 15%) with the wide and flat lower calyx infundibulum, and Type B2 (74/320, 23%) with the narrow and steep lower calyx infundibulum (*Figure 2B*). If two or three of the following three conditions are met: renal lower bifurcated branches of divided pelvis-to-UPJ cross-sectional area ratio >4, IUA >30°, IL <3 cm, the pelvis was considered to be type B1 which is relatively easy for lithotripsy. If none or one of the following three conditions mentioned above are met, the pelvis was considered to be type B2 which is relatively hard for lithotripsy. *Table 2* showed a summary
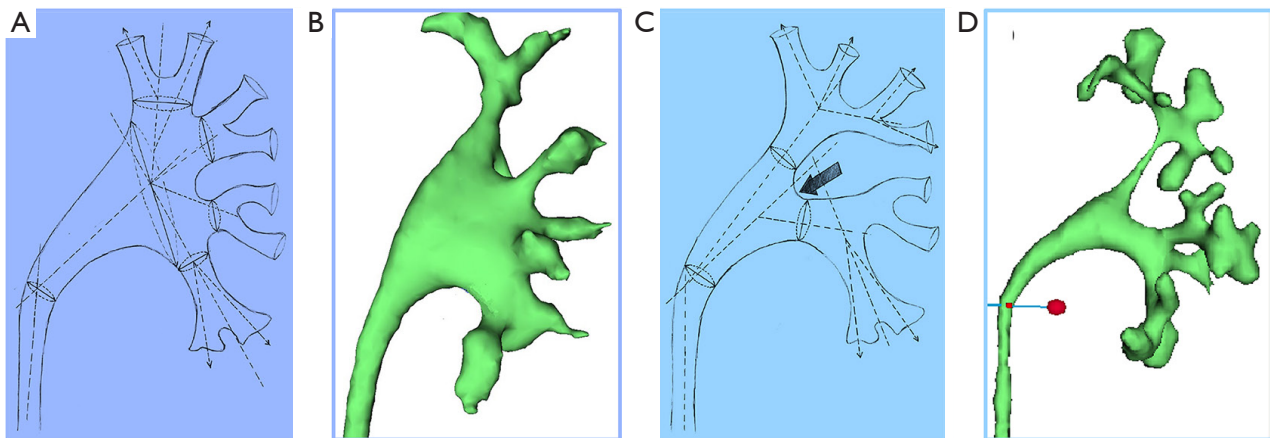
Figure 1 Model diagram and three-dimensional virtual reconstruction models of two modified Takazawa renal pelvicalyceal anatomical classification types. (A) Model diagram depicting Type A; (B) three-dimensional virtual reconstruction model of Type A; (C) model diagram depicting Type B; (D) three-dimensional virtual reconstruction model of Type B.
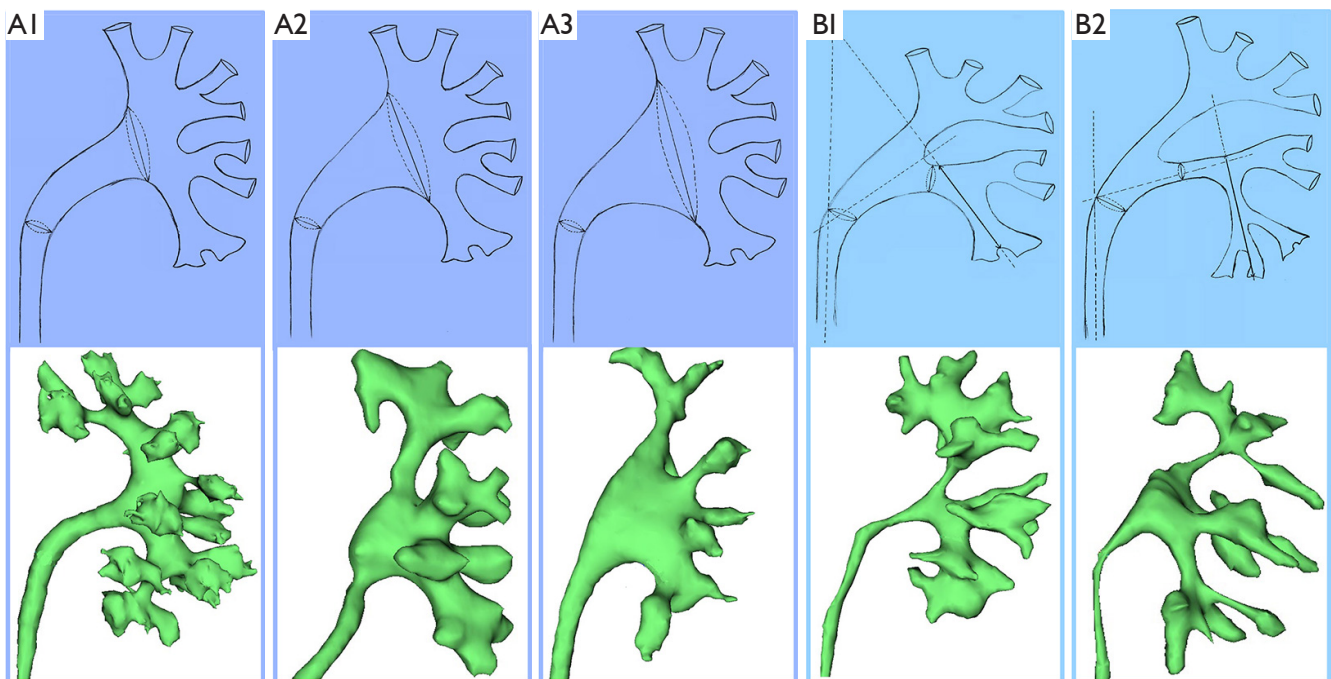

Figure 2 Model diagrams and three-dimensional virtual reconstruction models of five modified Takazawa renal pelvicalyceal anatomical classification subtypes. (A1) Type A1—renal pelvis-to-ureteropelvic junction (UPJ) cross-sectional area ratio ≤4. (A2) Type A2—renal pelvis-to-UPJ cross-sectional area ratio =4–16. (A3) Type A3—renal pelvis-to-UPJ cross-sectional area ratio ≥16. (B1) Type B1—two or three of the following three conditions are met [renal lower bifurcated branches of divided pelvis-to-UPJ cross-sectional area ratio>4, infundibuloureteral angle (IUA) >30°, lower pole infundibular calyceal length (IL) <3 cm]. (B2) Type B2—none or one of the following three conditions are met [renal lower bifurcated branches of divided pelvis-to-UPJ cross-sectional area ratio >4, IUA >30°, lower pole infundibular calyceal length (IL) <3 cm].

Table 2 Summary of the modified Takazawa anatomical classification of renal pelvicalyceal system based on three-dimensional virtual reconstruction models

Type	Proportion (%)	Clinical value	Definition
Type A	62	Single pelvis	
Type A1	22	Slimline pelvis	Cross-sectional area ratio of renal pelvis-to-UPJ ≤4
Type A2	27	Typical pelvis	Cross-sectional area ratio of renal pelvis-to-UPJ: 4–16
Type A3	13	Broad Pelvis	Cross-sectional area ratio of renal pelvis-to-UPJ ≥16
Type B	38	Divided pelvis	
Type B1	15	Easy for lithotripsy	2 or 3 of the following 3 conditions are met:
			Cross-sectional area ratio of lower bifurcated branches of divided pelvis-to-UPJ >4
			Infundibuloureteral angle (IUA) >30°
			Lower pole infundibular calyceal length (IL) <3 cm
Type B2	23	Hard for lithotripsy	0 or 1 of the following 3 conditions are met:
			Cross-sectional area ratio of lower bifurcated branches of divided pelvis-to-UPJ >4
			Infundibuloureteral angle (IUA) >30°
			Lower pole infundibular calyceal length (IL) <3 cm

UPJ, ureteropelvic junction.

of the modified classification system, and *Table 3* showed comparing morphological parameters of all modified renal pelvicalyceal classification types.

Discussion

The pelvicalyceal system consists of minor calyces, major calyces and the renal pelvis. Calyx is the cavity of the kidney, through which urine passes. The minor calyx is 7–13 in number and cup-shaped, surrounding the apex of renal pyramid (10). The neck of the minor calyx is a slimline structure, which is called infundibulum. Two or three minor calyces converge to form a major calyx, which enters renal pelvis with a certain angle (11). The pelvis is the funnel, like the upper end of a dilated ureter. The renal pelvis, the major calyces, the infundibula and the minor calyces are collectively called intrarenal pelvicalyceal system.

One of the most easily neglected aspects is the anatomy of renal pelvicalyceal system, during endourological removal of renal stone. Although many studies have reached some conclusions on the related factors, the gross anatomic variation of the renal pelvicalyceal system might be as numerous as fingerprint of an individual (12,13). The symmetry of the renal pelvicalyceal system of a single

individual on both sides is only about 37% (14). Not only is the position and number of different parts of the renal pelvicalyceal system different among individuals, but the parts could either be numerous or absent as well. The applied anatomy of the renal pelvicalyceal system, especially for the lower pole and inferior calyces, is still lack of large sample size analysis.

Surgeons, especially the junior with less experience in endourologic treatment, may disorientated in the renal pelvicalyceal system because they are not familiar with the anatomical characteristics of renal pelvis and calyces, which may affect the surgical efficacy, cause residual stones and even iatrogenic injury. For senior surgeons, although they may be familiar with the renal pelvicalyceal system, however due to the lack of scientific data support, these empirical understanding is often difficult to be promoted to the theoretical level. A comprehensive understanding of renal pelvicalyceal anatomy is essential for the interpretation of preoperative imaging examination and reliable endourological surgery. In order to help urologists to image the exact characteristics of the calyces and visualize the renal pelvicalyceal system in 3 dimensions, we conducted this systematical study of renal pelvicalyceal anatomy and detailed the modified Takazawa classification of that from

Table 3 Morphological parameters of various modified Takazawa renal pelvicalyceal classification types

Variable	Type A1	Type A2	Type A3	Type B1	Type B2
Number of renal pelvicalyceal system, n [%]	70 [22]	86 [27]	42 [13]	48 [15]	74 [23]
Number of major renal calyces, n	2.77±0.54	3.03±0.54	2.81±0.74	2.08±0.35	2.11±0.35
Cross-sectional area of UPJ, mm^2	25.61±16.85	11.91±7.97	3.73±2.89	11.81±14.37	16.93±15.01
Cross-sectional area of renal pelvis, mm^2	58.39±39.71	85.98±50.77	120.15±71.08	–	–
Cross-sectional area of upper bifurcated branches of divided pelvis, mm^2	–	–	–	12.75±10.89	14.26±11.87
Cross-sectional area of lower bifurcated branches of divided pelvis, mm^2	–	–	–	32.42±24.48	23.34±21.20
Angle between the central axis of renal pelvis and upper ureter (°)	133.24±12.27	134.30±15.40	135.41±17.31	139.03±11.93	130.99±13.04
IPA	88.78±16.31	82.57±15.24	78.04±15.68	99.30±17.57	91.06±17.93
IUA	43.87±19.57	38.58±16.93	33.44±19.79	58.33±17.50	42.05±23.23
IL, mm	30.86±13.29	30.21±10.07	28.84±9.26	24.69±9.81	34.03±12.99
Cross-sectional area of Infundibulum section of inferior calyx, mm^2	14.07±11.99	19.01±16.08	23.23±20.68	14.69±13.48	11.42±10.92

Data are presented in terms of mean ± standard deviation or the numbers of individuals. UPJ, ureteropelvic junction; IPA, infundibulopelvic angle; IUA, infundibuloureteral angle; IL, lower pole infundibular calyceal length.

3D virtual reconstruction models.

The kidney collecting system can be divided into many types according to the position and shape of renal pelvis, the pattern and length of drainage of calyces (*Table 4*). Bruce Sir *et al.* (15) observed that the location of renal pelvis as extrarenal, borderline or intrarenal. Graves (16) classified the pelvicalyceal patterns in different types according to the shape of the renal pelvis along with calyceal protrusion. Sampaio and Mandarim-de-Lacerda (14), based on polyester endocasts, provided the classification of the pelvicalyceal patterns in a variety of dimensions. They divided the pelvicalyceal system into four types according to the drainage of the mid (hilar) zone and of the polar regions. And Ningthoujam *et al.* (12) proposed another classification system, including bicalyceal, tricalyceal, and multicalyceal types. As far as the limitations of previous classifications of renal pelvicalyceal system are concerned, most classifications were based on endocasts which could change their shape on hardening, or based on two-dimensional images which may be not help for spatial anatomical visualization. The reason why the most of classifications are not sufficiently widespread is probably because it is difficult to understand the corresponding anatomical parameters of renal pelvis and calyces intuitively and precisely, and because it is limited in

clinical application, especially in endourological surgery.

In recent years, Japanese scholars Ryoji Takazawa *et al.* (17) proposed a nomenclature for renal calices, and simplified morphological classifications of the renal pelvis suitable for endourological surgery. The classification proposed by Ryoji Takazawa *et al.* makes up for the limitations of previous studies on renal pelvis and calyces, they classified minor calyx into five levels : top, upper, middle, lower, and bottom, which make it possible to share common intrarenal information. They also divided the renal pelvis into two major types based on Brödel's research: single pelvis and divided pelvis. Single pelvis was subdivided into three types based on the width of the single pelvis. This classification system could be useful for the planning endoscopic treatment strategies for renal stones. By means of analyzing, analogizing and summarizing the data of our center, we once again recognized the correctness of Takazawa's and Brödel's findings and proposed a modified Takazawa anatomical classification of renal pelvicalyceal system based on 3D virtualization technology. Our proposed two major types were consistent with their findings and we found the ratio of the two main types is similar to that of Japanese scholars. What is different and innovative, we incorporated the parameters of 3D virtual reconstruction

Table 4 Summary of renal pelvicalyceal classifications

Studies	Classifications
Bruce Sir 1967, (15)	Intrarenal
	Extrarenal
	Borderline
Grave 1954, (16)	Classic Y, Type A
	Inverted T, Type B
	Balloon, Type C
	Bagpipes, Type D
Sampaio 1988, (14)	Type A-I
	Type A-II
	Type B-I
	Type B-II
Ningthoujam 2005, (12)	Bicaliceal (Y-shaped)
	Tricaliceal (Triangular)
	Multicaliceal (Radiate)
Takazawa 2018, (17)	Type Ia
	Type Ib
	Type Ic
	Type II
Present study	Type A1
	Type A2
	Type A3
	Type B1
	Type B2

models as the basis for classification, meanwhile we described, analyzed and summarized the anatomy of lower pole calyx and infundibulum. We subclassified type B into two subtypes: Type B1 (15%) with the wide and flat lower calyx branch, Type B2 (23%) with the narrow and steep lower calyx branch which further improves the value of clinical application especially for lower pole calyceal calculi.

We believe that subclassification of type B will also be practical for endourological treatment strategies for lower pole calyx stones, since the stone treatment in the lower pole calyx is less successful and more difficult compared with other parts of the kidney (18). Research on the relationship between renal pelvicalyceal system anatomical characteristics and urolithiasis began with the pioneering

study of Aragao and Sampaio (19). Following studies have showed some lower pole pelvicalyceal anatomical features, such as infundibular calyceal width (IW), IL and IUA, which are important for stone clearance after retrograde intrarenal surgery (RIRS) and extracorporeal shockwave lithotripsy (ESWL). According to Elbahnasy (9), the following factors are believed to be beneficial to the removal of lower pole stones: IW >5 mm and IL ≤3 cm. On the contrary, IW ≤5 mm and IL >3 cm are considered as unfavorable factors. Geavlete *et al.* concluded that the IUA influences the performances of flexible ureteroscopy. They found that the larger the angle, the higher the success rate of lithotripsy in the treatment of lower calyces. When the angle is less than 30 degrees, it is usually difficult to treat the lower calyceal calculi with flexible ureteroscopy (20). Type B1 with flat IUA, large IW, and short IL is very likely to have complete removal of stone fragments, which is an appropriate case for RIRS and ESWL. On the other hand, the anatomic condition of type B2 patients is unfavorable, especially for narrow, long and steep infundibular, residual stones after ESWL are almost inevitable. Under these circumstances, alternative therapies such as ureteroscopy lithotripsy or PCNL are preferable, as these procedures are relatively insensitive to the negative anatomical factors. As far as we know, there has not been the research on the topic, and we have reported subclassification of lower pole infundibulum initially based on 3D virtual reconstruction models, which is of clinical value for clearance of lower pole renal calculi.

In accordance with the study of Takazawa, under the circumstance of Type A1, which is narrow pelvis, PCNL seems hard than typical or broad pelvis due to the restricted space. While ureteroscopy is performed in type A1, surgeons should pay more attention to distinguish renal pelvis from the ureter in order to avoid damage of renal pelvicalyceal system. Type A3, the broad pelvis, seems easier for PCNL to make relatively larger size tract. On the other hand, this type is easily confused with hydronephrosis and when ureteroscopy lithotripsy performed, stone dust or fragments may deposit down to the bottom.

Fine knowledge of the anatomy remains the cornerstone of surgery (2). The main limitation of the previous studies was the two-dimensional features by anatomical measurements through urography (21). In our study, CTU makes it possible to perform measurements in 3D virtual reconstruction models, which has proved to be a useful method for analyzing intrarenal and extrarenal anatomical characteristics (22,23). In previous studies, liquid rubber

was injected into the renal pyelocaliceal system to produce endocast reprints. The technique can clarify the intrarenal relationship between the injected cavities but neglected the extrarenal relationship with the rest of the body. Due to the shrinkage of rubber after hardening or expansion at higher pressure while injecting, it is also easy to produce errors (14,24,25). In our study, 3D virtual reconstruction models can make up for the above two defects of endocast, and could enable a clear understanding of the pelvicalyceal anatomy.

However, our study had several limitations. First, our study is retrospective and limited to the 320 images of kidneys after approximately 12% of kidneys were excluded due to anatomical distortion (hydronephrosis or large renal cysts) or insufficient image quality. Similar to the research of Japanese scholars, our research objects are all East Asian races, thus prospective research covering different races needs to be further carried out. Second, by referring to the previous literatures on the anatomy of kidney collective system, we analyzed, analogized and summarized the data of our center, and then put forward the modified Takazawa anatomical classification. However, describing the classification based on the location of calyces and the shape of pelvis, it is hardly novel. By the means of 3D virtual reconstruction models, we made efforts to involve anatomical information of the lower pole infundibulum and to provide spatial anatomical parameters such as area of renal pelvis and UPJ, so that urologists can intuitively understand the anatomy and make preoperative plan for endourological lithotripsy. Third, the clinical utility of the modified classification system needs further research. Although many studies have compared different treatment options for kidney stones, most studies have not studied the renal pelvicalyceal anatomy that would predict the success of these treatments. In the next step, we plan to validate the system in a multicenter study and explore the impact of each morphological classification on endourological treatment efficacy.

Conclusions

Previous studies have reported that the visualization and classification of renal pelvicalyceal anatomical structure by corrosion cast, autopsy, ultrasonography and excretory urography, the modified Takazawa anatomical classification of renal pelvicalyceal system based on 3D virtual reconstruction models enables to standardized different anatomical morphology of renal pelvicalyceal system and provide intuitive and concise information of lower pole infundibulum anatomy, therefore leading to the improvement of endourological lithotripsy.

Footnote

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