The Anatomic Structure of a Fused Renal Pyramid and Its Clinical Significance in the Establishment of Percutaneous Renal Access

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OBJECTIVE To explore the clinical significance of the fused renal pyramid (FRP) in establishing percutaneous renal access, and the anatomic basis for avoiding vascular injury caused by puncturing through this renal pyramid with the aim of achieving accurate puncture in percutaneous nephrolithotomy.

MATERIALS AND METHODS Sixty-two cadaveric kidneys and 105 porcine kidneys were selected for the assessment of regional anatomy, to explore the anatomic structure of the FRP and determine its frequency. Then, we compared the effects of 4 different puncture paths on the occurrence of renal vascular injury when respectively punctured through the normal renal pyramid (group A), the centerline of one side pyramid of the FRP (group B), the center of the entire FRP (group C) and the renal column (group D).

RESULTS The incidence of FRP in human kidneys is not low. The artery in the kidney can be divided into 6 grades. The grade IV branch-interlobar artery courses through the FRP. There was significant difference in the degree of arterial injury between the group A and C ($P = .003$), while no significant difference between the group A and B ($P = .151$). There was significant difference in the proportion of interlolar artery injury between group A and C ($P < .001$), while no significant difference between group A and B ($P = .239$).

CONCLUSION It is necessary to carefully identify and bypass the FRP when establishing a percutaneous renal access. If unavoidable, the puncture path should be on the centerline of one side pyramid of the FRP. UROLOGY 124: 38−45, 2019. © 2018 Elsevier Inc.

Clinical anatomy is an important basis for the continuous development of urology, and the innovative progress of percutaneous nephrolithotomy (PCNL) cannot be separated from the anatomy of the kidney and its complicated anatomic relationship.[1] Despite the considerable progress that has been made in the current technology and equipment, approximately one-fourth of patients still experience postoperative complications (23.3%),[2] with bleeding (8.5%) being the most common.[3] Puncture bleeding has a great impact on the treatment and prognosis of patients and represents the biggest challenge during the surgical procedure.[4] A meta-analysis of multicenter showed that the average blood transfusion rate after PCNL is 7%,[5] although conservative treatment can control most bleeding, some patients (0.9%) still require surgical intervention, such as superselective arterial embolization, due to severe bleeding.[6]

While bleeding is affected by a variety of factors, vascular injury along the puncture access route is the most direct and important reason.[7] Based on the safety principles of the kidney's vascular anatomy, percutaneous renal puncture is usually chosen in the area with relatively few blood vessels, such as the Brodel avascular plane.[8] Furthermore, the interlobar artery distributes in the renal column while the renal pyramid is relative avascular area, which can minimize vascular injury and avoid bleeding when puncturing through the renal pyramid. The normal renal pyramid (NRP) presents a one-to-one relationship between pyramid and minor calyx. In theory, a puncture path through the centerline of NRP will transit through the axis line of the corresponding minor calyx, which is the minimum damage line to renal vessels when performing puncture. Generally, it is the calyx rather than the NRP that is easy to serve as a puncture landmark under X-ray or ultrasound guidance. We have demonstrated that punctured through the axis line of the target calyx under

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ultrasonography-guided was a safe and effective way to establish percutaneous renal access.[9]

Although we have achieved a fairly safe and accurate PCNL, puncture bleeding is still difficult to avoid in clinical work. Combined with clinical practice, we found that the fused renal pyramid (FRP) is an important cause of puncture bleeding. The FRP refers to 2 or more adjacent pyramids fused together in the medullary layer of the kidney. The FRP loses the one-to-one relationship between pyramid and minor calyx, and there is no obvious dividing line between the renal papillae, which enter together to the same minor renal calyx, namely, the fused minor renal calyx (FRC). Since the FRP does not affect the function of kidney, there are few studies on its anatomic structure and blood vessel distribution. Routinely puncture guided by the FRC and neglecting the potential vascular variation may result in serious injury to the ectopic interlobar artery in FRP. The aim of this paper is to explore the anatomic structure of the FRP and to study the resultant vascular injury after puncturing through the FRP, thus delineating a complete and reliable anatomic basis for a more accurate puncture.

MATERIALS AND METHODS

Anatomy

Sixty-two intact cadaveric kidneys were selected for fine anatomy and were numbered and marked with their position. The pelvises of the kidney specimens were dissected in a longitudinal line, and then all minor renal calyces and their fornix were fully exposed. The morphological structure of all the renal pyramids were evaluated and were cut open to judge whether or not they were FRPs. In addition, 105 fresh pig kidneys were selected from a commercial pig slaughterhouse, and the same experimental method was used for anatomy, though the renal pyramid was not cut open.

At the same time, the regional anatomy of FRP's blood vessel distribution was investigated. The tissue block containing the FRP was completely dissected, and tissue sections were obtained along the confluent surface of the FRP and subjected to hematoxylin-eosin (HE) staining.

Puncture and Vascular Injury

During the anatomic analysis of the above 105 pig kidneys, 80 of them were selected to simulate percutaneous renal puncture. We have established a total of 160 puncture accesses, divided into groups A, B, C and D, with 40 in each group. Group A was punctured through the center of the NRP. Group B and C both have the FRPs in the middle group calyx. Group B was punctured through the centerline of one side pyramid of the FRP, group C was punctured through the center of the entire FRP. Group D was punctured through the renal column (Fig. 1A). The puncture sites for all 4 groups were in the middle group calyx near the Brodel plane. The same surgeon simulated percutaneous renal puncture and dilatation with an Amplatz sheath or fascial dilator to gradually establish a 24Fr operational access under ultrasonography-guided, and then evaluated the vascular injury endoscopically. Then, the tissue block containing the access was completely cut down. Tissue sections vertical to the access were obtained and underwent HE staining. We selected the section that would make the main vessel and the access as close as possible. At least 3 sections were selected for each access, 1 for the renal medulla, 1 for the junction of the cortex and medulla, and 1 for the renal cortex. Finally, the tissue sections were evaluated by the same experienced pathologist who was blinded to the group assignment.

The risk of vascular injury was evaluated mainly to determine 3 aspects under the endoscope and microscope: (1) whether there was vascular distribution along the operational access, (2) whether the distribution of blood vessels was injured, and (3) the distance between the puncture access and the main blood vessel. In the absence of direct vascular injury, the distance between the main vessel and percutaneous renal access is closer and the risk of puncture bleeding is greater.

Statistical Analysis

The number of renal pyramids, minor renal calyces, and major renal calyces were counted and added up, the apparent position was recorded, and the fused degree as well as the fused pyramidal number of FRP in each kidney was counted, from both the pig and cadaver kidneys. With the aid of vascular casting, we graded the kidney's arteries to quantify the risk of vascular injury. The grade of injured artery and the corresponding number of access in the above 4 groups were statistically analyzed. According to the grade of the injured artery, the rank transformation was performed, and the data of 4 groups were reranked for comparison. Chi-square test, *t* test and Rank sum test were used for statistical test, a P value <.05 was considered statistically significant.

RESULTS

The Frequency of FRP

In the case of the middle group calyx, the fused degree of the FRP was different and could be roughly divided into 3 degrees: mild, moderate, or severe (Fig. 1B). The fused degree and the fused number of FRP in the middle group calyx were not significantly different between the human and porcine kidneys (P = .708 and .720, respectively). The incidences of FRP were extremely high in the upper and lower group calyxes, in which 3 or more pyramids often severely merged into a large flake (Fig. 1C). For cadaveric kidneys, the incidence of FRP in the middle group calyx was 21.0%, which was significantly lower than those in the upper or lower group calyxes (P <.001; Fig. 1D; Table 1).

The Vascular Anatomy of FRP

For the vascular anatomy of the FRP, the pig kidney was basically the same as the human kidney. The artery in the kidney can be divided into 6 grades (Fig. 2A). The grade IV branch-interlobar artery was distributed inside the FRP with unclear boundary (Fig. 2B). HE staining showed that, for the FRP, the ectopic interlobar artery often developed abnormally, nearly naked and without protection from the connective tissue and coursed into the FRP directly (Fig. 2C). For cadaveric kidneys, the average diameter of interlobar artery in the FRP was significantly smaller than that in the renal column ([0.784 ± 0.046] mm vs [1.358 ± 0.042] mm, [P <.001]).

Vessels Injuries in Different Puncture Paths

In group A, the breakthrough sense of puncture was obvious, and there was no injured blood vessel distributed along the access that was observed with the endoscope. HE staining showed that

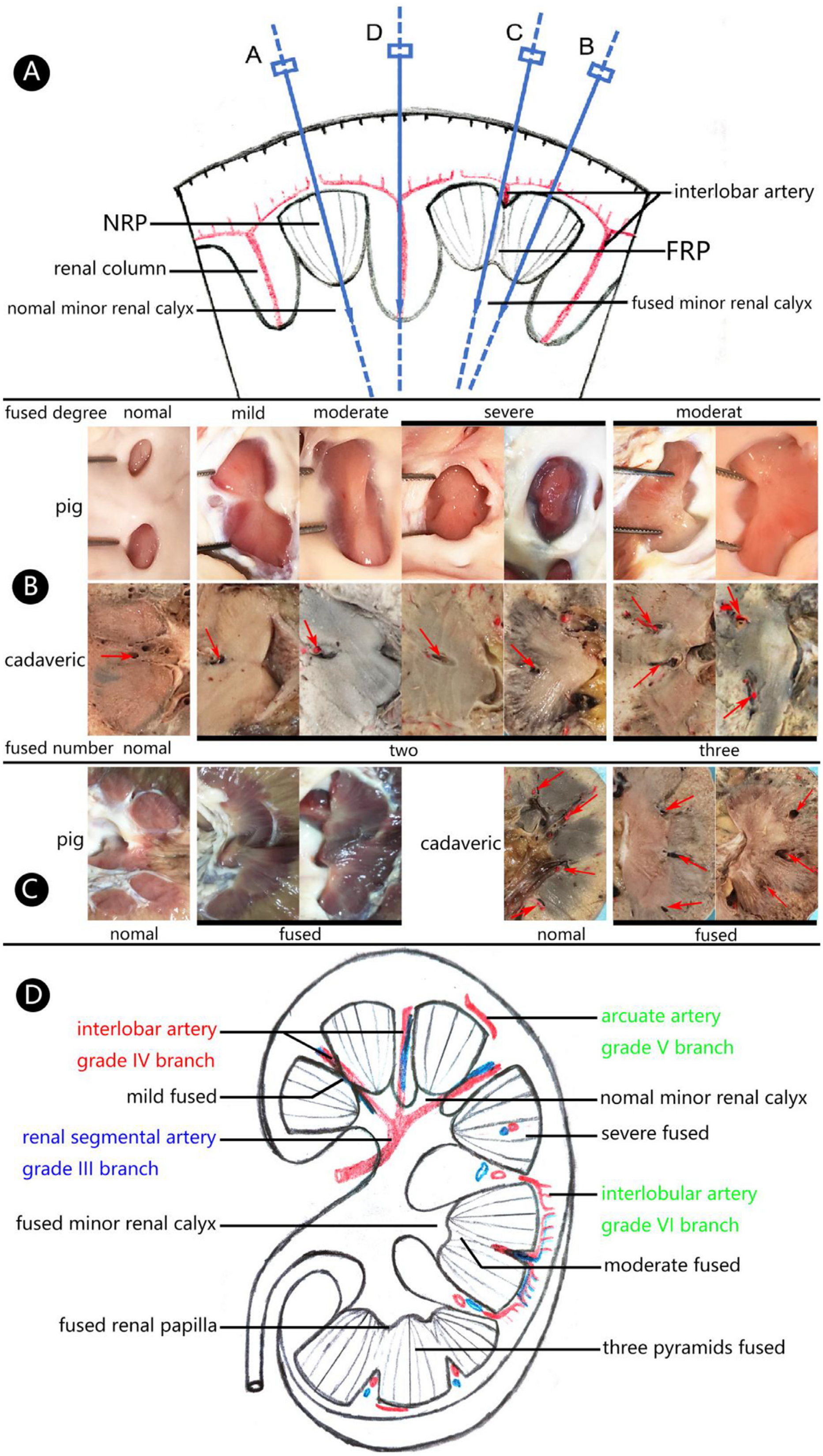

Figure 1. (**A**) Puncture path schematic. Group A was punctured through the center of the NRP. Group B was punctured through the centerline of one side pyramid of the FRP. Group C was punctured through the center of the entire FRP. Group D was punctured through the renal column. (**B**) The anatomic features of FRP in the middle group calyx, including the fused degree and the fused pyramidal number. The red arrow indicates the interlobar artery distributed in the renal column or FRP. (**C**) The anatomic features of FRP in the upper and lower group calyxes. The red arrow indicates the interlobar artery distributed in the renal column or FRP. (**D**) The anatomic schematic of FRP. FRP, fused renal pyramid; NRP, normal renal pyramid.

Table 1. The related variables of FRP in pig and human kidney

Variables	Pig	Human	*P* Value
Renal pyramid (*n*)	17-25	10-20	<.001
Minor renal calyx (*n*)	8-15	6-14	<.001
Major renal calyx (*n*)	2	2-3	<.001
The incidence in different group calyx (%)			
Upper group calyx	96.2	67.7	<.001
Middle group calyx	70.5	21.0	<.001
Lower group calyx	97.1	64.5	<.001
In the upper and lower group calyx			
Fused pyramidal number of FRP (%)			.403
2	28.6	38.7	
3-5	71.4	61.3	
In the middle group calyx			
Fused pyramidal number of FRP (%)			.720
2	88.6	88.2	
3	11.4	11.8	
4 and above	0	0	
Fused degree of FRP (%)			.708
Mild	13.4	17.6	
Moderate	36.9	35.3	
Severe	49.7	47.1	

FRP, fused renal pyramid.

there was also a certain distance between the renal column and the tract, but in rare cases there was still injury (Fig. 3A).

In group B, though there was a certain distance between the tract and the grade IV branch that distributed in the FRP, injury was still present (Fig. 3B).

In group C, there was a white thin strip of connective tissue exposed along the operational access under endoscopy. HE staining revealed that the puncture often directly injured the grade IV branch. In severe cases, the blood vessel was even cut transversely (Fig. 3C).

The dilated resistance of group D was obvious. There were grade III-VI arteries distributed along the access, which was covered with white fat and connective tissue (Fig. 3D).

The mean ranks of arterial injury degree in groups A (53.20), B (69.38), C (81.70), and D (94.34) gradually increased, and the difference was statistically significant (P <.001). After adjusted the P value using the Bonferroni correction, a P value <.0083 was considered statistically significant. There was no significant differences between the group A and B (P = .151), the group C and D (P = .083), the group B and C (P = .181), the group B and D (P = .012). There was significant differences between the group A and C (P = .003).

The proportion of grade IV artery injury in group A, B, C and D was significant different (P <.001). There were significant differences between the group A and C (12.5% vs 67.5%, P <.001), the group B and C (22.5% vs 67.5%, P <.001). There was no statistical difference between group A and B (P = .239). There were injuries to grade V and VI arteries in the 4 groups, and the difference was not significant (P = .924; Fig. 3E; supplement table 1).

DISCUSSION

In PCNL, the ideal access can completely clear stones while minimizing postoperative complications. However, punctures that do not follow the anatomy of the kidney may lead to many complications, such as bleeding during and after surgery, damage to the kidneys and nearby organs, etc.[5] In fact, there are many anatomic correlative factors affecting PCNL,[10] such as the morphological structure of the collecting system and its relationship with the distribution of blood vessels.[11] Among these, the FRP is the most often neglected important anatomic structure,[12] although the diameter of interlobar artery in the FRP is relatively small. It must be noted that as long as renal pyramids occur fused together, there must be an anatomic marker, namely, a vascular path surrounded by a small amount of connective tissue.

In the experiment, there is no problem judging the grade of the injured artery based on the tissue sections. Although the distribution of the grade III branch in the pig kidney is slightly different from that in the human kidney, the distribution of arteries in grade IV-VI branches is completely consistent.[13] The grades of the injured arteries can be determined by microscopic identification of the renal cortex, renal medulla, and renal column. The interlobar artery is mainly distributed in the renal column or the FRP of the renal medulla layer. For a long time, the cause of post-PCNL bleeding has often been attributed to problems related to the surgery itself, such as inaccurate locating, excessive diameter and a greater number of access routes.[14] Moreover, the degree of vascular injury is more often judged by the amount of blood loss.[15] The grade of injured arteries in the operational access has been rarely studied or analyzed. Grading kidney arteries not only helps to identify the grade of injured artery, but also to quantify the degree of vascular injury in PCNL.[16]

The true anatomic basis for PCNL is to select the renal pyramid instead of the renal column as the puncture site.[17] Although the injury proportion of interlobar artery in group B and C was statistically significant, the difference in total arterial injury was not significant. This is

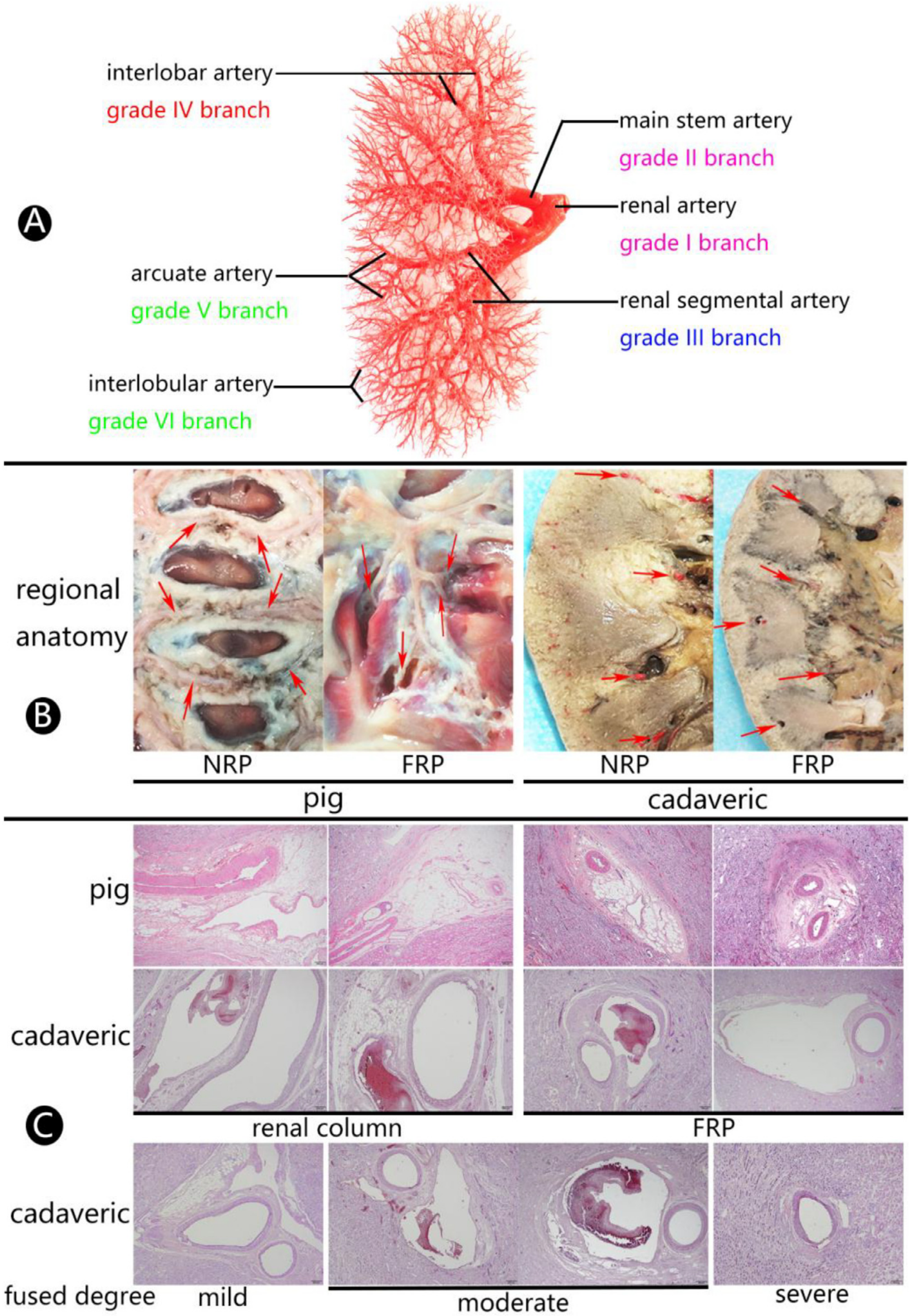

Figure 2. (**A**) Grading of kidney arteries. The artery in the kidney can be divided into 6 grades, the grade I branch is renal artery, the grade II branch is anterior or posterior main artery, the grade III branch is renal segmental artery, the grade IV branch is interlobar artery, the grade V branch is arcuate artery and the grade VI branch is interlobular artery. (**B**) The vascular anatomy of NRP and FRP. The red arrow points to the artery between NRPs or in FRP. The ectopic interlobar artery was distributed inside the FRP with unclear boundary. (**C**) The interlobar artery in FRP and renal column (HE $\times$ 40). Scale bar: 200 μm. The average diameter of interlobar artery in the FRP was significantly smaller than that in the renal column (P <.001).

related to the fact that the puncture path is closer to the renal column in group B, which may increase the risk of vascular injury in the renal column.

Combined with clinical practice, injury to the blood vessels in the FRP may not lead to immediate bleeding. More often, it may lead to delayed bleeding, the development of postoperative arteriovenous fistulas and intrarenal pseudoaneurysms which greatly impact patient prognosis and may even require interventional therapy.[18,19] This study explains the risk of vascular injury associated with different puncture pathways. However, the presence of risk does not necessarily mean that an injury will occur. More importantly, the study provides a more complete anatomic basis for percutaneous renal puncture and allows

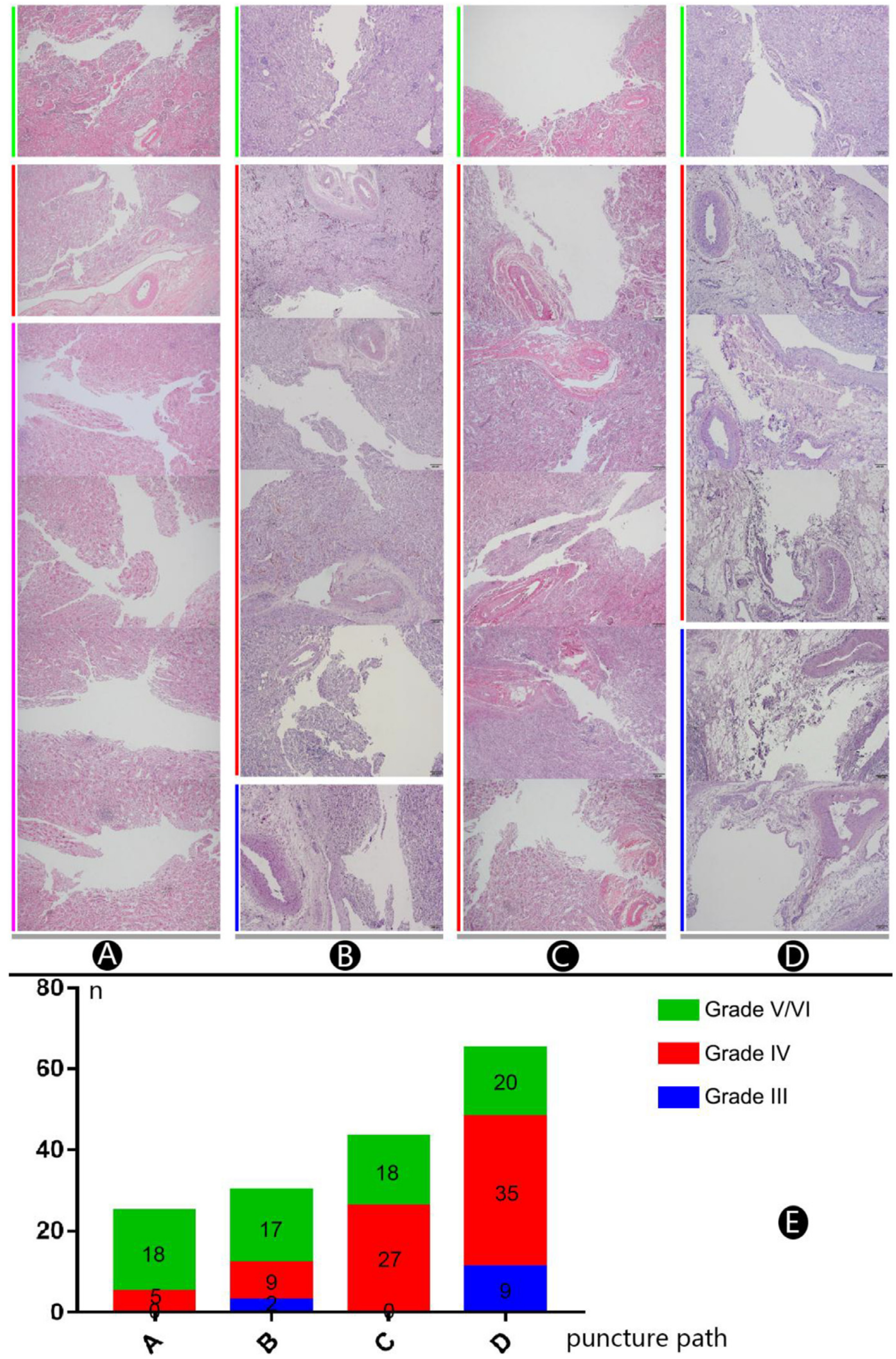

Figure 3. (**A-D**) The grade of the injured artery in 4 groups (HE × 40). Scale bar: 200 μm. Pink line indicates avascular injury, blue lines indicate grade III arterial injury, red lines indicate grade IV arterial injury, and green lines indicate grade V/VI arterial injury. (**A**) Group A was punctured through the center of the NRP. (**B**) Group B was punctured through the centerline of one side pyramid of the FRP. (**C**) Group C was punctured through the center of the entire FRP. (**D**) Group D was punctured through the renal column. (**E**) The grade of the injured artery and the corresponding number of access in 4 groups. The *x*-axis represents different puncture paths. The *y*-axis indicates the number of access with arterial injury. The same access may have different grades of arteries that were injured at the same time.

the surgeon to be aware of the surgical risk while planning the puncture path, so that timely adjustments can be made.

The puncture sites of the 4 groups were all in the middle group calyx, which can reduce intergroup errors due to differences in puncture sites. At present, it is more common to establish percutaneous renal access in the middle posterior group renal calyx.[20] Some studies have shown that upper pole percutaneous renal access for nephrolithotomy has an acceptable complication risk when managing large burden, complex stones.[21] Our study shows that there is no Brodel line in the upper and lower pole of kidney. Furthermore, compared with the middle group calyx, the incidence of FRP in the upper and lower group calyces is much higher, and the structure is more complicated. Theoretically, the risk of puncture bleeding is higher than that in the middle group renal calyx.

Establishing a targeted access from the skin to a specific renal calyx is a critical step in PCNL and requires a thorough understanding of renal, retroperitoneal, and thoracic anatomy to minimize the risk of complications.[22] The establishment of percutaneous renal access under ultrasound guidance has been widely used. This technique mainly relies on the apex of the minor renal calyx's fornix to target the puncture point.[23,24] For NRP and mildly fused pyramid, ultrasound guided puncture is safe and efficient. However, ultrasound is still difficult to distinguish the severe fused type clearly. If the puncture targeting calyx is a FRC, then the axis line of the calyx may coincide with the midline of the FRP containing of 2 renal pyramids and the risk of vascular injury will increase significantly.

The access diameters established in the 4 groups of this experiment were all 24Fr. The main reason is that the 24Fr access is part of the standard renal access and is relatively common in surgery because it is easy to control the relevant variables.[25] A dilation tract up to 24Fr is indeed the critical point for many complications.[26] Subsequent studies may design accesses of other sizes. Inaccurate locating will increase the risk of vascular injury in PCNL.[27] Literature suggests that, under 30Fr access, the infundibular approach to the posterior middle renal calyces is not associated with higher blood loss in comparison to the approach to the fornix of the papilla under fluoroscopy-guided.[28] However, neither of these 2 approaches considered the effect of FRP on bleeding. In addition, it should be noted that the overdilated diameter may partially obscures the difference in results due to the difference in the approach.

The incidence of the FRP in the human body is not low, but the recognition rate of FRP in vitro is still low clinically, whether by using ultrasound or X-ray. Relatively speaking, there are 2 ways to distinguish the FRP. One is to observe the morphological structure of the renal papilla under the endoscope. However, the accuracy of this method is low and it is invasive. The second is to use a renal enhanced CT. During the cortical phases, the renal cortex and the renal column are markedly enhanced,[29] while the FRP shows a large area of low density shadow. There is also a point-like obvious enhancement shadow in the near bottom of FRP, which is a distributive trace of the interlobar artery (Supplement Fig. 1).

A limitation of the current study is that due to the limited number of cadaveric kidney specimens, the incidence of FRP in this experiment may not accurately represent the occurrence in the population. Given the need to evaluate vascular injury in the trial, evaluation criteria need to be further standardized to ensure that the favorable outcomes can be replicated by the other puncture techniques before we can accurately identify the FRP. An additional limitation is that this study was performed in isolated pig kidneys, which limited the clinical value of the study results. Subsequent experiments required consideration of a live animal study with histologic examination to corroborate the findings. Furthermore, we are still investigating how to use the ultrasound and X-ray to identify the FRP clearly and apply it to clinical practice to assist the surgeon in designing a safe puncture path more accurately.

CONCLUSION

In summary, FRP is one of the common anatomic structures of the human kidney. The mutated interlobar artery lacks the necessary protection as it is distributed inside the FRP. The puncture which was carried out through the center of the entire FRP will significantly increase the risk of vascular injury. Therefore, it is necessary to carefully identify and bypass the FRP when choosing a puncture path. If unavoidable, it may be safer to puncture through the centerline of one side pyramid of the FRP, rather than the axis of the FRC.

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SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.urology.2018.11.004.

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