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The Pig Kidney as an Endourologic Model: Anatomic Contribution

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ABSTRACT

We present detailed anatomic findings on collecting system anatomy and renal morphometry in the pig and compare these findings with previous findings in humans. We studied three-dimensional polyester resin corrosion endocasts of the pelviocaliceal system obtained from 100 kidneys (50 pigs). Eighty kidneys were evaluated morphometrically, considering length, cranial pole width, caudal pole width, thickness, and weight. The pig collecting system was classified into two major groups (A and B). Group A (40%) was composed of kidneys in which the mid-zone is drained by calices dependent on the cranial or the caudal caliceal group or both. Group B (60%) kidneys have the mid-zone drained by calices independent of the polar groups. Group B includes two subtypes (B-I and B-II). The pig collecting system showed only angles smaller than 90° between the caudal (lower) infundibulum and the renal pelvis. Renal morphometric measurements revealed the following means: length 11.8 cm, cranial pole width 5.64 cm, caudal pole width 5.35 cm, thickness 2.76 cm, and weight 98 g. As in human kidneys, one may group the pig collecting system into two groups. Nevertheless, in pigs, we did not find a subdivision of Group A. The incidence of collecting systems in Groups A and B and the subtypes of Group B in pigs are different from those in humans. Also different from humans, in pigs, we found only angles smaller than 90° between the caudal (lower) infundibulum and the renal pelvis. Except for the length, the means of the other morphometric measurements of the pig kidney are smaller than those of humans. From an anatomic standpoint, despite the differences pointed out, we conclude that the pig kidney is a good animal model for endourologic research and training.

INTRODUCTION

THE KEY TO UNDERSTANDING the clinical significance of various new technologies is the establishment of valid animal models.[1–4] The remarkable applications of new instrumentation techniques and less-invasive surgical procedures to treat renal diseases, such as laparoscopy, endourology, extracorporeal lithotripsy, percutaneous therapy, nephron-sparing surgery, laser techniques, stapling devices, stents, etc., require an ideal animal model of the kidney to test the techniques and instruments in the laboratory setting.[1–8] In the field of endourology, an adequate experimental model of the human kidney would be very helpful for training in percutaneous access and intrarenal surgery.[9]

The pig is replacing the rabbit and dog as an experimental urologic model and has been widely used in experimental works and training. The pig is believed to be the ideal model for urologic and endourologic research because it has renal anatomy and physiology similar to those in man. Swine kidneys, like human ones, are multipapillary, whereas the rat, rabbit, and dog have unipapillary kidneys.[2,4,7] Owing to the resemblance to the human kidney, the possibility that in the near future the pig could be a potential kidney donor for man has recently been mentioned in the literature.[16]

Although the pig kidney has been well studied in terms of physiology (renin–angiotensin system, dynamics of urine transport, etc.),[6,8] there are no specific anatomic studies on the pig kidney. The data available are very generic and do not assist urologic research.[11–17] Recently, an elegant work on the intrarenal arteries of the pig kidney was published;[18] nevertheless, no specific data are available on the pelviocaliceal system and morphometric measurements of the pig kidney. We believe

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that additional detailed anatomic studies are necessary for enhancing the applications of experimental endourologic techniques in the laboratory and its transfer to the clinical realm.

This study aimed to present detailed anatomic findings on collecting system anatomy and renal morphometry in the pig and compare these findings with previous findings in humans.

MATERIAL AND METHODS

Our material consisted of nonfixed kidneys obtained from 50 adult mixed-breed Duroc and Large-White farm pigs. The pigs were slaughtered at 140 days, when the body weight ranged from 60 to 80 kg (mean 72 kg). Sex was not considered because the males had been castrated after birth.

Collecting System Anatomy

We studied the pig collecting system in 100 three-dimensional endocasts of the pelviocaliceal system according to the technique described previously.[19–21] Briefly, a polyester resin (volume approximately 7.0 mL) was injected into the ureter to fill the kidney collecting system. Added to the resin was a methylethylperoxide as a catalyst in a proportion of 3% of injected resin. Because the polyester resin is translucent, a yellow pigment was added in order to obtain opaque casts (more appropriate for analysis than translucent casts). After injection and setting of the resin (24 hours), the perirenal fat was removed, and the specimens were immersed in a bath of concentrated commercial hydrochloric acid for 48 hours until total corrosion of the organic matter was achieved, leaving only the endocasts of the collecting system. Because polyester resin polymerizes by addition of a catalyst, there is no shrinkage on setting, enabling accurate analysis on the endocasts.[18–20] In addition to the qualitative analysis of the endocasts, we measured the angle formed between the main caudal (lower) infundibulum and the renal pelvis.[22]

Morphometric Analysis

After removal of the perirenal fat and the pedicle components, 80 kidneys (from 40 pigs) were quantitatively evaluated considering the following measures: greatest longitudinal length, cranial pole width (greatest width cranial to the hilum), caudal pole with (greatest width caudal to the hilum), thickness, and weight.[23,24] Because the kidneys were weighed after the injection of the resin, to obtain the real kidney weight, we subtracted the weight of the corresponding endocast from the kidney weight obtained initially. All measurements were made by the same researcher using a digital caliper ruler and a digital balance with a precision of 0.01 g. A statistical evaluation of the renal measurements was made considering the mean, the standard deviation, the coefficient of variation, the correlation coefficient of Pearson (r), and Student's *t*-test.[25]

RESULTS

Anatomic Classification of the Pelviocaliceal System

The pelviocaliceal endocasts were divided into two major groups according to the drainage of the polar regions and the mid-zone. Group A was composed of 40 casts in which the mid-zone was drained by calices that were dependent on the cranial or on the caudal caliceal groups. The mid-zone drainage could also be dependent on the cranial and caudal caliceal groups simultaneously (Fig. 1A,B). Group B was composed of 60 casts in which the kidney mid-zone was drained by calices that were independent of the cranial and caudal caliceal groups. Group B included two types (varieties) of pelviocaliceal systems. In type B-I (six casts), the mid-zone was drained by a major caliceal group independent of both the cranial and the caudal group and entering directly into the renal pelvis (Fig. 1C). In type B-II (54 casts), the kidney mid-zone was drained by minor calices (one to five) entering directly into the renal pelvis (Fig. 1D). Such calices were independent of both the cranial and the caudal caliceal groups.

Special Features of the Pelviocaliceal System

In 18 casts (18%), there was a perpendicular minor calix draining into either the renal pelvis or a major calix (Fig. 2). The number of minor calices in one cast was amply varied (4 to 19). The cranial polar region presented more minor calices than the caudal polar region (Table 1).

In all casts, an angle smaller than 90° was formed between the axis of the main caudal infundibulum and the renal pelvis.

The morphology of the kidney collecting system is varied and is not symmetrical. We found pelviocaliceal systems with morphologic bilateral symmetry in only 56% of the cases (28 pairs of casts).

Renal Morphometric Analysis

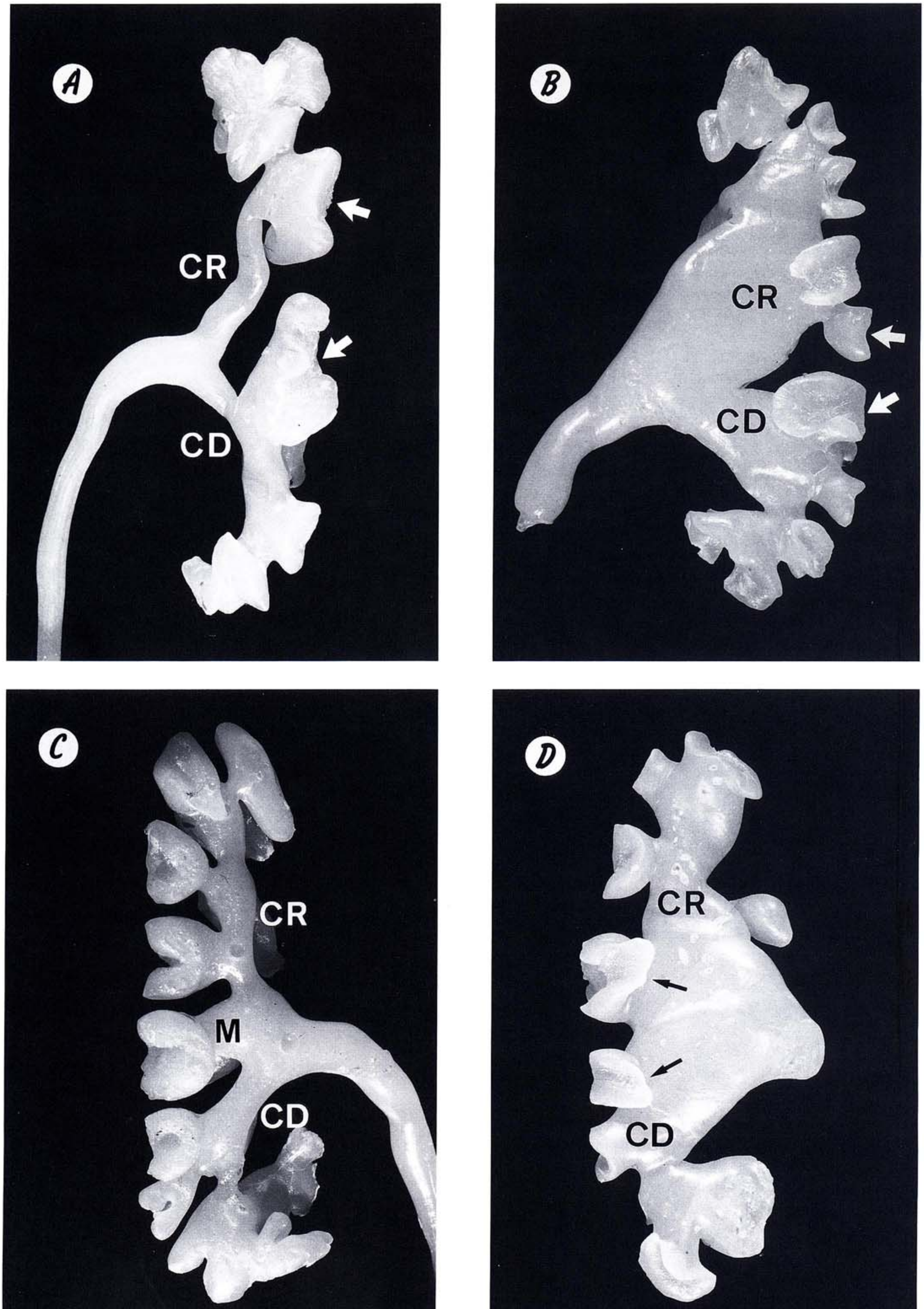
The statistical analysis of the renal morphometric measurements is indicated in Table 2.

DISCUSSION

Anatomic Classification of the Kidney Collecting System

Proposed for the first time for swine, the present classification of the pelviocaliceal system into two groups (A and B) according to the drainage of the polar regions and the mid-zone

FIG. 1. Polyester resin corrosion endocasts of pig pelviocaliceal system. A. Ventral view of Group A endocast from left kidney shows mid-zone drained by calices dependent on cranial (CR) and caudal (CD) caliceal groups (arrows). Note that cranial and caudal infundibula are long and thin. B. Ventral view of Group A endocast from left kidney shows mid-zone drained by calices dependent on cranial (CR) and caudal (CD) caliceal groups (arrows). Note that cranial and caudal infundibula are short and thick. C. Ventral view of Group B (B-I) endocast from right kidney shows mid-zone drained by hilar major calix (M) independent of cranial (CR) and caudal (CD) caliceal groups. Note that cranial and caudal infundibula are long and thin. D. Ventral view of Group B (B-II) endocast from right kidney shows mid-zone drained by minor calix entering directly into renal pelvis, independent of cranial (CR) and caudal (CD) caliceal groups.


A
CR
CD
B
CR
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C
CR
M
CD
D
CR
CD

is similar to and agrees in some aspects with the classification proposed previously for humans.[19,26]

Group A, which was composed of pelviocaliceal systems that presented two major caliceal groups as a primary division of the renal pelvis and mid-zone drainage dependent on these major groups (see Fig. 1A,B), included 62% of the kidneys in humans, whereas in pigs, it included only 40%. Different from the human collecting system, in the pig kidney, we did not find a subdivision for the collecting systems in Group A. In humans, we have described a subdivision of Group A (type A-II), occurring in 17% of the cases, in which the kidney mid-zone is drained by crossed calices, one draining into the superior caliceal group and another draining into the inferior caliceal group simultaneously. The crossing calices (laterally) and the renal pelvis (medially) bound a region (space) that we denominated in humans the interpelvic–caliceal (IPC) space.[19,26] In pigs, the existence of the IPC space was not observed.

Group B, composed of pelviocaliceal systems that present kidney mid-zone drainage independent of the polar caliceal groups (Fig. 1C,D), includes 38% of the kidneys in humans,[19,20,26] whereas in pigs, it included 60% of the specimens. Type B-I, composed of kidneys in which the mid-zone is drained by a major caliceal group independent of the polar groups (Fig. 1C), includes 21.5% of the kidneys in humans[19,26] and only 6% of those in pigs. The more frequent type of collecting system in pigs was type B-II (54% of the specimens), composed of kidneys in which the mid-zone is drained by one to five minor calices entering directly into the renal pelvis, independent of the polar caliceal groups (Fig. 1D). Type B-II occurs in only 16.4% of the cases in humans.[19,26] Therefore, the mid-zone structure is more likely to be a major calix in humans and a minor calix in pigs.

Special Features of the Pelviocaliceal System

In the pig kidney, we found a perpendicular minor calix draining directly into the renal pelvis or into a major calix in 18% of the cases (see Fig. 2). We have described the presence of such minor calices in 11.4% of the kidneys examined from humans.[20] The perpendicular minor calices can be superimposed on other structures, and because of this fact, identification of these calices radiographically can be difficult.[20]

The number of minor calices per collecting system in the pig ranged from 4 to 19 (mean 8.6), very similar to the number in humans, which ranges from 5 to 14 (mean 8.2).[19] In the pig, the cranial pole presented more minor calices than the caudal pole ($p < 0.01$).

Regarding the angle formed between the main caudal (lower) infundibulum and the renal pelvis, whereas in humans, it may assume values either greater or smaller than 90°,[21,27] in the pig, we found only angles smaller than 90°. Therefore, pigs would not serve as a good model for lower-pole fragment-clearance rates.

Similar to humans, the pelviocaliceal system in the pig is amply varied, and we found collecting systems presenting long and thin caliceal infundibula (see Fig. 1A) and collecting systems presenting short and thick infundibula (see Fig. 1B). Also, as we have shown previously in humans,[19,20] there is no bilateral symmetry of collecting system structures in the pig kidney. We found bilateral symmetry in 56% of the cases in pigs and in 37.1% of the cases in humans.[19,20]

The spatial orientation of the pig caliceal system is very similar to that of the human collecting system, and we found the calices oriented in the dorsal and ventral position relative to the abdominal plane.

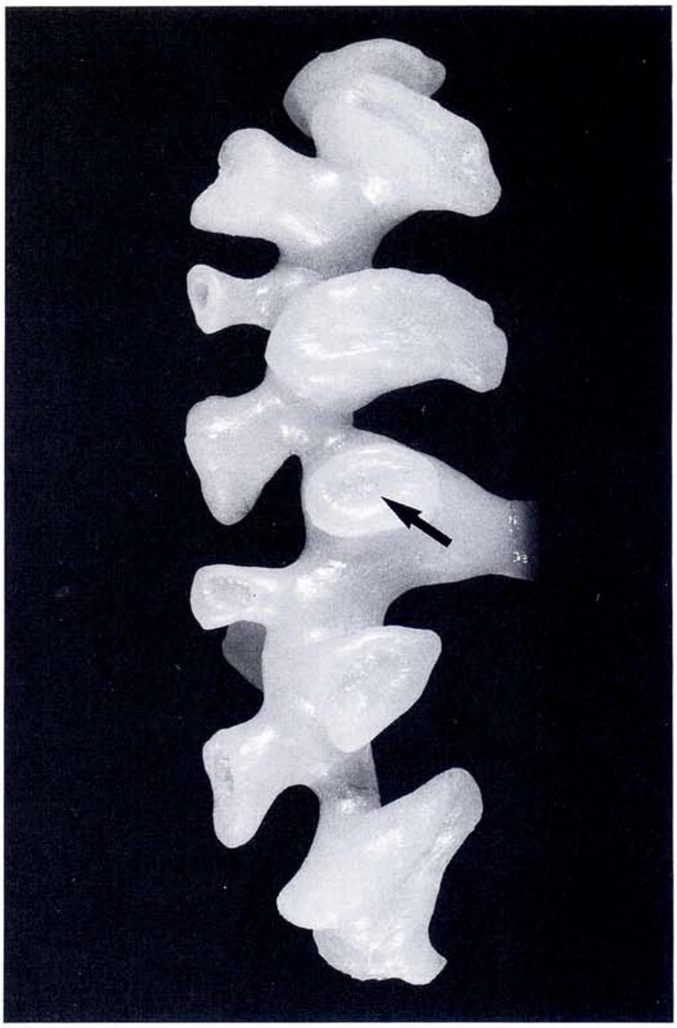

FIG. 2. Anterior view of left polyester resin corrosion endocast of pig pelviocaliceal system reveals perpendicular minor calix draining directly into dorsal surface of renal pelvis (arrow).

Pig Kidney Morphometry

Our results related to the weight of the pig kidney (mean 98 g) are not in agreement with those of earlier authors, who report weights ranging from 200 to 250 g,[14] 150 to 200 g,[11] 200

TABLE 1. NUMBER OF MINOR CALICES BY CAST

	Group A (N = *40)*			*Group A* (N = *60)*			
	*CR**	*CD†*	*By Cast*	*CR**	*M‡*	*CD†*	*By Cast*
Mean	5.0	3.6	8.6	4.3	1.65	2.7	8.65
SD	2.12	1.93	3.51	1.92	0.88	1.11	2.89
Maximum	10	9	17	12	5	5	19
Minimum	2	1	4	2	1	1	4

*CR = cranial pole.
†CD = caudal pole.
‡M = mid-zone.

TABLE 2. RESULTS OF MORPHOMETRY FOR RIGHT AND LEFT KIDNEYS

	Length (cm)		*Cranial Pole Width (cm)*		*Caudal Pole Width (cm)*		*Thickness (cm)*		*Weight (g)*	
	Right	*Left*	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*
Mean	11.62	11.96	5.63	5.65	5.42	5.27	2.83	2.68	99.05	97.32
SD	1.07	1.02	0.57	0.62	0.52	0.52	0.52	0.49	17.91	18.4
CV%*	9.21	8.53	10.12	10.97	9.59	9.87	18.37	18.28	18.08	18.91
Maximum	13.69	13.82	6.89	6.95	6.67	6.82	3.93	3.73	136.11	131.18
Minimum	9.65	9.7	4.23	3.96	4.17	4.23	1.73	1.78	56.23	58.59

*Coefficient of variation.

to 280 g,[16] and 150 to 280 g.[15] Those authors did not describe the animals' breed, weight, or age. Also, it was stated that the relation between the kidney weight and the body weight in adult animals is 1:150 to 1:200;[14] nevertheless, we found a relation of 1:373.

Getty[14] reported 12.5 cm for kidney length and 6.0 to 6.5 cm for the largest width. Schwarze and Schröder[13] gave 12.0 to 13.0 cm for kidney length, with the width ranging from 6.0 to 7.0 cm. These texts present general descriptions and do not consider the differences between cranial and caudal pole width in the same kidney. We did not find any citation in the literature describing the difference between cranial and caudal pole width, such as we show in Table 2.

We found a general mean of 11.8 cm for pig kidney length, which is very similar to that of humans (11.1 cm).[23,24] The left kidney length exceeded that of the right kidney, but the difference was not statistically significant. The width of the cranial pole was greater than the width of the caudal pole, and this difference was statistically significant. Interestingly, this finding is in agreement with previous original findings in humans.[21,23] We found that in the pig, the means of the measures for the cranial pole width (5.64 cm), the caudal pole width (5.35 cm), and the thickness (2.76) are smaller than those in humans: 6.44 cm, 5.49 cm, and 3.29 cm, respectively.[21,23] Although these differences are statistically significant, one may consider that the morphometry of the pig kidney is very similar to that of the human kidney.

In conclusion, the pig kidney collecting system is similar in many aspects to the human collecting system. Also, pig kidney morphometry presented results very similar to that of humans. From an anatomic standpoint, because of its similar collecting system and its similar size, the pig kidney should be a good model for general urologic research as well as for endourology and extracorporeal shockwave lithotripsy research.[5,6,8] We believe that the knowledge of the precise collecting system anatomy and renal morphometry in the pig will be of great value for future experimental designs in urologic research.

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