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PIG KIDNEY: ANATOMICAL RELATIONSHIPS BETWEEN THE INTRARENAL ARTERIES AND THE KIDNEY COLLECTING SYSTEM. APPLIED STUDY FOR UROLOGICAL RESEARCH AND SURGICAL TRAINING

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ABSTRACT

Purpose: We present a systematic study of the anatomical relationships between intrarenal arteries and the kidney collecting system in pigs.

Materials and Methods: The intrarenal anatomy (collecting system and arteries) was studied in 91, 3-dimensional endocasts of the kidney collecting system together with the intrarenal arteries.

Results: Some anatomical details that have importance to help research and surgical training in urology when using the pig as an animal model were observed and described. It was found that there was only 1 artery per kidney. This artery divided into cranial and caudal branches in 85 cases (93.4%). In 6 cases (6.6%) the primary division of the renal artery was in a dorsal and in a ventral branch. In all cases 2 arteries (1 ventral and 1 dorsal) involved the cranial caliceal group. In the dorsal mid zone a dorsal artery originated from the cranial division of the renal artery, which was obliquely positioned in 47.25% of cases. The arterial supply related to the ventral mid zone of the kidney consisted of branches that coursed horizontally in the ventral surface of the renal pelvis in 81.32% of cases. The caudal division of the renal artery supplied the ventral and dorsal surfaces of the caudal caliceal group in 84.62% of cases, while in 15.38% a dorsal artery supplied its dorsal surface.

Conclusions: Although the results of renal and intrarenal anatomy in pigs could not be completely transposed to humans, many similarities in the pig and human intrarenal arteries support its use as the best animal model for urological procedures.

KEY WORDS: kidney; swine; models, animal; laparoscopy; education

Many animals have been used as experimental models for urological procedures but the pig is used more often because its kidney is the one that most closely resembles the structural features of human kidney.[1] The anatomy of the arterial and collecting system of the human kidney has been well studied in the past[2–5] as well as the applied anatomy of these structures.[6–8]

Anatomical knowledge about the intrarenal arteries is important for performing intrarenal surgeries with minimal blood loss and minimal injury to adjacent parenchyma.[9] The possibility of significant bleeding and injury to the remaining parenchyma during open or laparoscopic partial nephrectomy makes it a technically challenging operation.[10]

Since the first laparoscopic nephrectomy in pigs[10] and soon after the first laparoscopic nephrectomy in humans,[11] the pig has been used as the favorite animal model for training and experimental research in urology, including many studies of laparoscopic total and partial nephrectomy as well as hemostasis techniques.[12–18] Although in the past some studies of pig kidney anatomy were published,[1,18] the urological literature still lacks a thorough analysis of the intrarenal vascular and pelvicaliceal anatomy in swine. We present a systematic study of the anatomical relationship between the intrarenal arteries and the collecting system in 3-dimensional endocasts of the porcine kidney to help urologists in experimental research and surgical training when using the pig as animal model.

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MATERIALS AND METHODS

Our material consisted of nonfixed kidneys taken from adult, mixed breed Duroc and Large White farm pigs slaughtered at age 140 days and weighing 60 to 80 kg (mean 72). The institutional animal review committee approved the research protocol.

The intrarenal anatomy (collecting system and arteries) was studied in 91 (46 right and 45 left) 3-dimensional endocasts of the kidney collecting system together with the intrarenal arteries obtained according to a previously described technique.[3,4,7,8] Briefly, to obtain the endocasts a yellow polyester resin (volume 2 to 6 ml) was injected into the ureter to fill the kidney collecting system and a red resin (volume 5 to 8 ml) was injected into the main trunk of the renal artery to fill the arterial tree. Added to the resin was a methyl ethyl peroxide as a catalyst in a proportion of 3% injected resin. After injection and setting of the resin (24 hours) the perirenal fat was removed and the kidneys 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 3-dimensional endocasts of the systems that had been injected. To preserve the same relationships as those that existed in vivo during cast preparation 1 or 2 arterial branches were fixed to the collecting system. Because the polyester resin polymerizes by addition of a catalyst, there is no shrinkage on setting, enabling accurate analysis of the endocasts.[3,4,7,8]

RESULTS

We observed only 1 artery per kidney. It divided into cranial and caudal branches in 85 cases (93.4%). In 6 cases (6.6%) the primary division of the renal artery was in a dorsal and in a ventral branch.

Cranial pole. There were 2 main arteries in the cranial pole (1 ventral and 1 dorsal). They were present in all cases and could have different origins but they usually arose from the cranial division of the renal artery. The cranial caliceal group was involved by these arteries, which originated in the interlobar arteries between the minor calices (fig. 1, *A* and *B*).

In 30 cases (32.97%) we observed the apical artery in the medial margin of the cranial pole. It could have different origins but usually arose from the cranial division of the renal artery. The apical artery passed far from the cranial infundibulum to reach the extremity of the cranial pole (fig. 1, *C* and *D*).

Dorsal mid zone (hilar). There were 1 or 2 main arteries in the dorsal mid zone of the kidney. These arteries passed obliquely on the dorsal surface of the renal pelvis. In 43 cases (47.25%) a dorsal artery originated from the cranial division of the renal artery, positioned obliquely in the caudolateral direction. In 29 cases (31.87%) there was also only 1 branch originating from the caudal division of the renal artery, positioned obliquely in the craniolateral direction. In 19 cases (20.88%) we noted each artery (figs. 1, *C* and 2).

Ventral mid zone (hilar). The arterial supply related to the ventral mid zone of the kidney was made by branches that coursed horizontally in the ventral surface of the renal pelvis. In 55 cases (60.44%) only 1 branch was observed, although in 19 (20.88%) we found 2 branches. These arteries arose from cranial or caudal division of the renal artery, or from the 2 divisions (fig. 3, *A* and *B*). On the other hand, in 17 cases (18.68%) only 1 branch from the cranial division of the renal

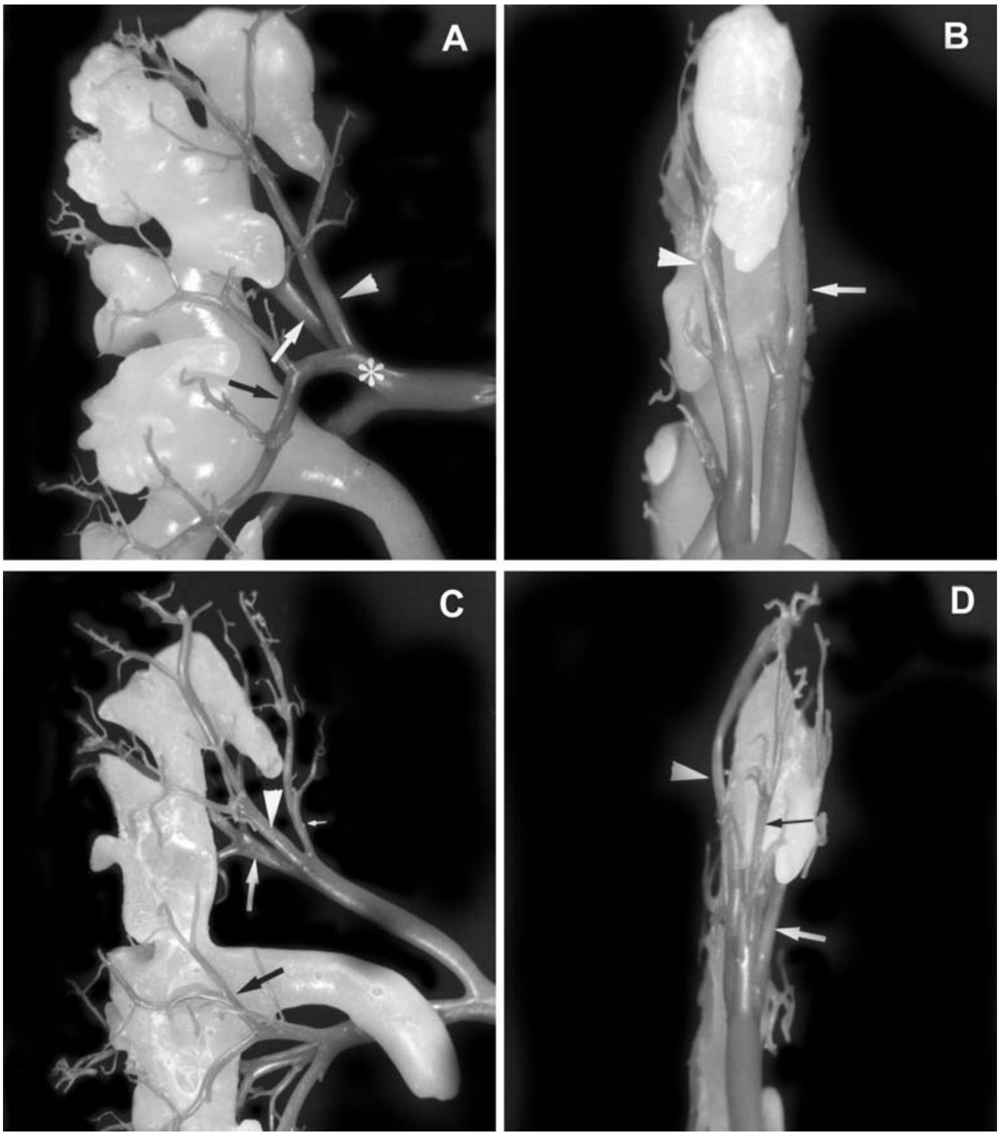

FIG. 1. Endocast (pelvicaliceal system and arteries) of pig left kidney. *A*, dorsal view shows arterial supply related to cranial caliceal group. Cranial division of renal artery (asterisk) divides into dorsal (arrowhead) and ventral (white arrow) branch. Dorsal artery (black arrow) arises from renal artery cranial division and courses obliquely on renal pelvis dorsal surface to reach caudal caliceal group. *B*, medial view demonstrates dorsal (arrowhead) and ventral (arrow) branches of renal artery cranial division. These arteries encircle cranial caliceal group. *C*, dorsal view reveals apical artery (short arrow), and dorsal (arrowhead) and ventral (arrow) branches of renal artery cranial division. Artery to dorsal mid kidney arises from renal artery caudal division and courses obliquely on renal pelvis dorsal surface (black arrow). *D*, medial view demonstrates apical artery (black arrow), and dorsal (arrowhead) and ventral (white arrow) branches of renal artery cranial division.

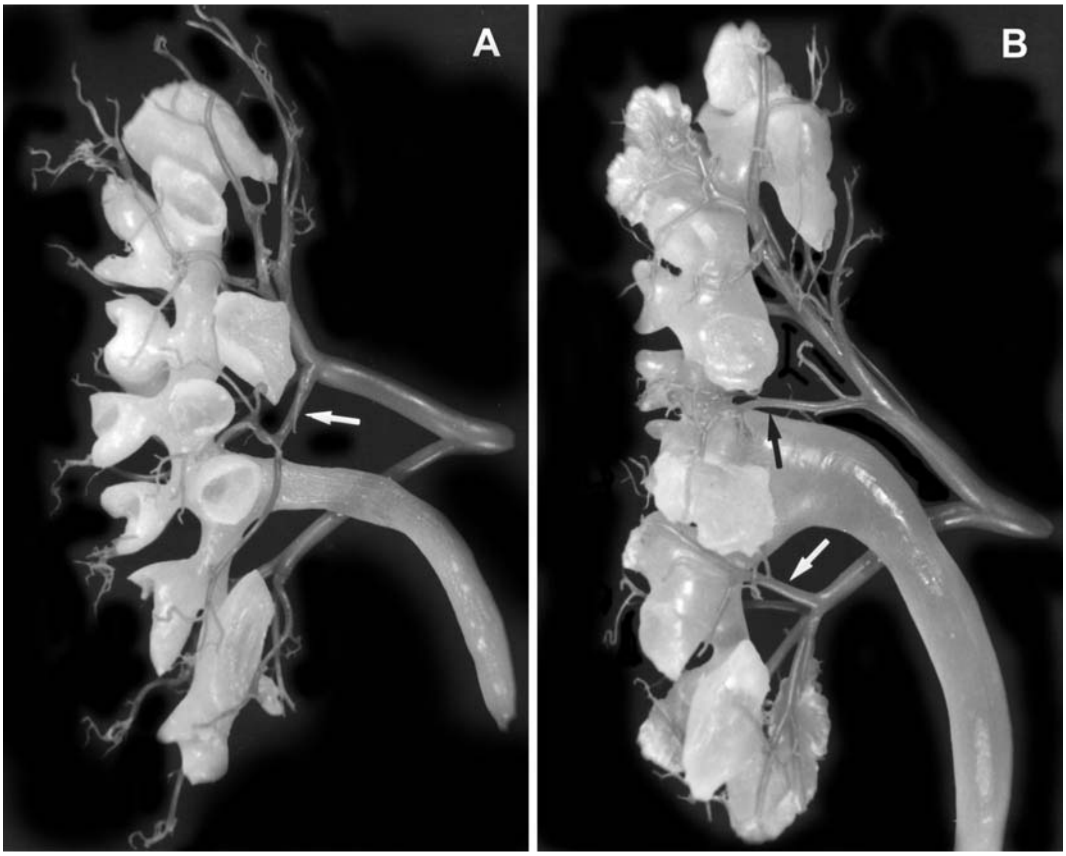

FIG. 2. Dorsal view of endocast (pelvicaliceal system and arteries) of pig left kidney. *A*, dorsal mid kidney is supplied by dorsal artery (arrow), which courses obliquely on renal pelvis dorsal surface. Note long cranial collecting system infundibulum in pigs. *B*, 1 cranial (black arrow) and 1 caudal (white arrow) oblique artery supplies dorsal mid kidney.

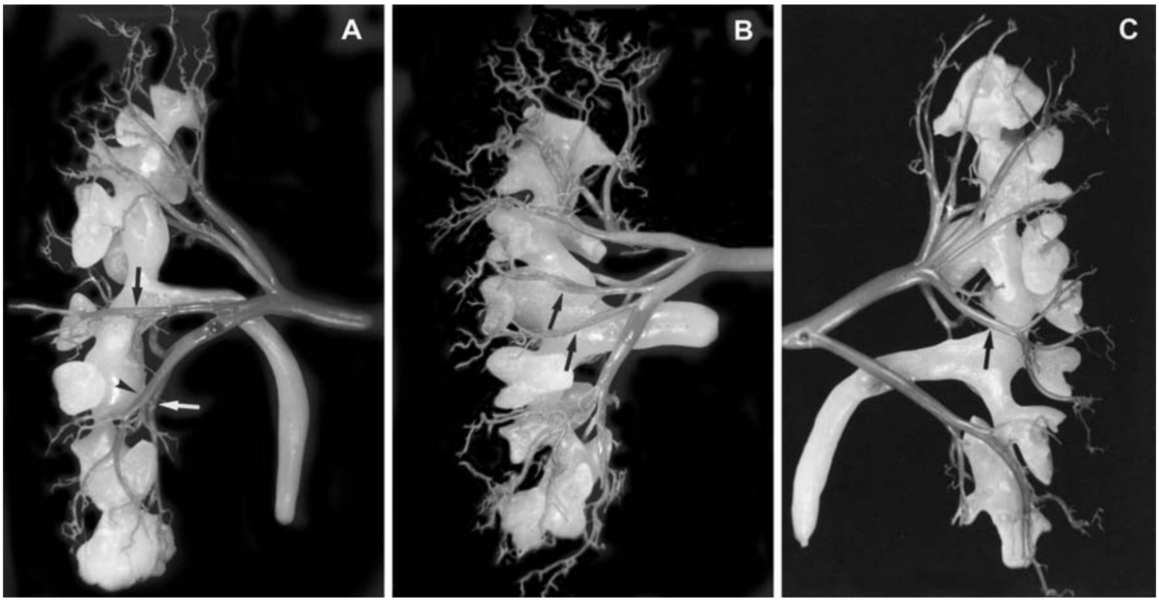

FIG. 3. Ventral view of endocast (pelvicaliceal system and arteries) of pig kidneys. *A*, in right kidney 1 artery (black arrow) supplies ventral mid kidney, which passes horizontally on renal pelvis ventral surface. Arterial supply related to caudal caliceal group is composed of ventral (arrowhead) and dorsal (white arrow) branches originating from renal artery caudal division. *B*, in right kidney 2 arteries (arrows) supply ventral mid kidney, passing horizontally on renal pelvis ventral surface. *C*, in left kidney 1 artery (arrow) supplies ventral mid kidney, coursing obliquely on renal pelvis ventral surface.

artery was found, which coursed obliquely on the ventral surface of the renal pelvis in the caudolateral direction (fig. 3, *C*).

Caudal pole. The caudal division of the renal artery supplied the ventral and dorsal surfaces of the caudal caliceal group in 77 cases (84.62%). This vessel passed ventral to the ureteropelvic junction and after entering the caudal pole it divided into a ventral and a dorsal branch (fig.3, *A*).

In the remaining 14 cases (15.38%) the caudal division of the renal artery supplied only the ventral surface of the caudal caliceal group and its extremity. The dorsal surface

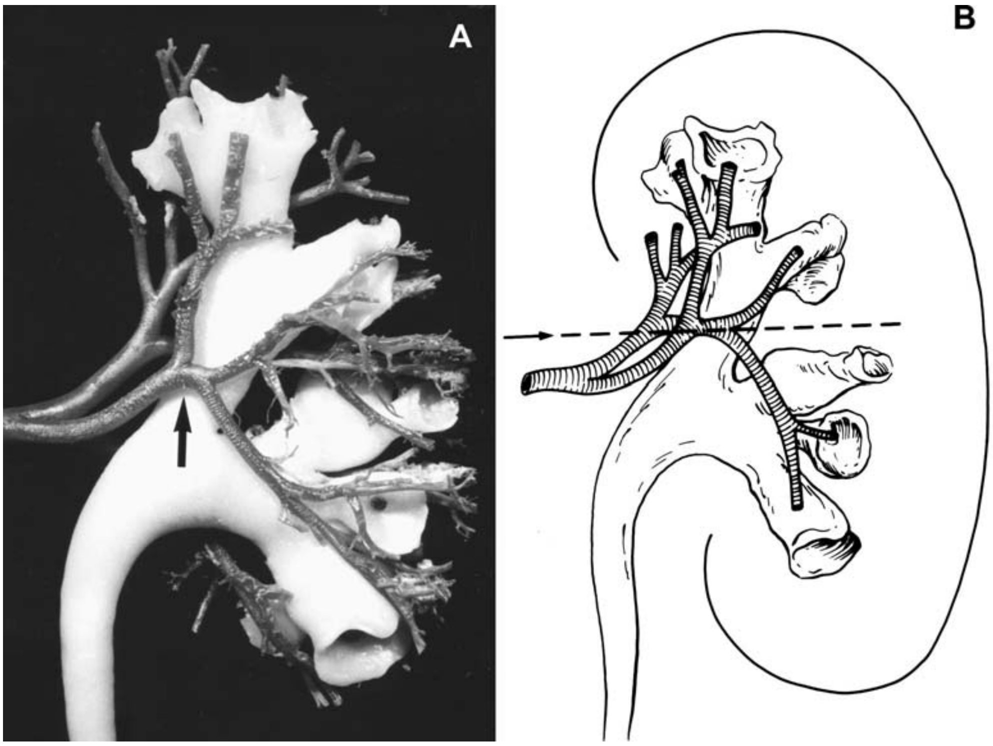

FIG. 4. Posterior view of endocast (pelvicaliceal system and arteries) of human right kidney. *A*, posterior segmental artery (retropelvic artery) describes arc and contacts upper infundibulum (arrow). *B*, incision line (arrow) for performing partial nephrectomy in superior pole may injure posterior segmental artery.[8]

was supplied by a dorsal artery, which arose from the cranial division of the renal artery and passed dorsal to the ureteropelvic junction (fig. 1, *A*).

DISCUSSION

In pigs a single renal artery was found in all cases, a number that is quite different from that in the human kidney, in which we found multiple renal arteries in 27% to 30%.[5,6] This fact is important consider when performing laparoscopic training in pigs for living donor nephrectomy, because in pigs the surgeon does not face a situation that is quite common in laparoscopic donor nephrectomy in humans, that is multiple renal arteries.[19,20] We also found primary division of the pig renal artery into a cranial and a caudal branch in 93.4% of cases, while primary division of all human renal arteries when there was a single artery was into an anterior and a posterior branch.[3]

The pattern of kidney segmentation in humans has been described as formed by 4[2] or 5[4] arterial segments. Using casts of the arterial system of the porcine kidney Evan et al observed that the renal artery branches into upper and lower polar arteries, and each of them divides into anterior and posterior segmental arteries.[18] They found differences between the branching pattern of the pig renal artery and the pattern described for the human renal artery.[2,4,18]

Sampaio and Aragão established the anatomical relationships between the intrarenal arteries and the kidney collecting system, and studied separately the superior pole, mid zone (hilar), inferior pole and dorsal kidney.[3] In the current study we considered the same relationships that Sampaio and Aragão established and we found many resemblances between pig and human segmental arteries.

In the cranial (superior) pole we found 2 main arteries (1 ventral and 1 dorsal), which originated from the cranial division of the renal artery and involved the cranial caliceal group, similar to what occurs in humans.[3] The apical artery was present in 32.97% of the pigs, while this artery was present in all humans.[3]

In the dorsal mid zone (dorsal kidney) the dorsal artery was found in 47.25% of cases, while this artery is found in all humans.[3] In the ventral mid zone (mid kidney) there was only 1 horizontal branch in 60.44% of cases, as in the human kidney (64.6%).[3]

In the caudal (inferior) pole the caudal artery divided into ventral and dorsal branches, which supplied the ventral and dorsal caudal caliceal groups in 84.62% of cases, while in the human kidney it occurred in 62.2%.[3] In the remaining 15.38% of pigs and 37.8% of humans[3] the ventral branch arose from the caudal artery and the dorsal branch arose from the dorsal artery.

As in the human kidney, punctures in the pig kidney should be made as far peripheral as possible, ideally through the caliceal fornix.[7] Punctures in the cranial infundibulum are dangerous because it is encircled by the ventral and dorsal branches of the cranial division of the renal artery (fig. 1, *B*). Direct puncture in the renal pelvis may result more often in a vascular complication than a transparenchymal caliceal approach, as in the human kidney, because the posterior artery may be injured. In pigs the dorsal artery crossed the dorsal surface of renal pelvis in 47.25% (fig. 1, *A*). Different from humans, the posterior segmental artery (dorsal artery) in pigs curved at the hilum giving branches to the mesorenal region and progresses to the caudal pole.

In humans it was demonstrated that the posterior segmental artery itself was in close relationship to the upper infundibulum or to the junction of the pelvis with the upper infundibulum in 57.3% (fig. 4, *A*). Hence, this artery is at risk during upper collecting system handling.[8] In humans resection of the kidney superior pole without previous dissection of the posterior segmental artery (blind resection), especially close to the hilum, may cause a lesion to this vessel because it may describe an arc that contacts the upper infundibulum (fig. 4, *B*). It was also demonstrated that injury to the posterior segmental artery (retropelvic artery) in humans, in addition to severe hemorrhage, can be associated with loss of a great portion of functioning renal tissue due to renal infarction. In some cases the posterior segmental artery may supply up to 50% of the renal parenchyma (median area of the posterior segment 33.56%).[4] Different from humans, in pigs the main trunk of the dorsal artery (posterior segmental artery) is not related to the upper infundibulum, which is long in pigs (fig. 2, *A*). Consequently in pigs snare assisted laparoscopic nephrectomy, for example, may be harmless without compromising the remaining renal vasculature and parenchyma. For that reason the technique and results of experimental nephrectomy in the superior pole (cranial pole) in pigs cannot be completely transposed to humans and this fact must be strongly considered by those involved in laparoscopic surgery training. On the other hand, the results of experimental nephrectomy in the inferior pole (caudal pole) in pigs may be similar to that in humans due to its similar intrarenal vascular anatomy. In conclusion, although the results of renal and intrarenal surgery in pigs could not be completely transposed to humans, many similarities of the pig and human intrarenal arteries support its use as the best animal model for urological procedures.

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