Anatomical Relationship Between the Kidney Collecting System and the Intrarenal Arteries in the Sheep: Contribution for a New Urological Model

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ABSTRACT

Previous studies have demonstrated that the pig collecting system heals after partial nephrectomy without closure. Recently, a study in sheep showed that partial nephrectomy without closure of the collecting system resulted in urinary leakage and urinoma. The aim of this study was to present detailed anatomical findings on the intrarenal anatomy of the sheep. Forty two kidneys were used to produce tridimensional endocasts of the collecting system together with the intrarenal arteries. A renal pelvis which displayed 11–19 (mean of 16) renal recesses was present. There were no calices present. The renal artery was singular in each kidney and gave two primary branches one to the dorsal surface and one to ventral surface. Dorsal and ventral branches of the renal artery were classified based on the relationship between their branching pattern and the collecting system as: type I (cranial and caudal segmental arteries), type II (cranial, middle and caudal segmental arteries) or type III (cranial, cranial middle, caudal middle, and caudal segmental arteries). Type I was the most common branching pattern for the dorsal and ventral branches of the renal artery. The arterial supply of the caudal pole of the sheep kidney supports its use as an experimental model due to the similarity to the human kidney. However, the lack of a retropelvic artery discourages the use of the cranial pole in experiments in which the arteries are an important aspect to be considered. Anat Rec, 299:405–411, 2016. © 2016 Wiley Periodicals, Inc.

Key words: sheep kidney; anatomy; collecting system; intrarenal arteries; animal model

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The open partial nephrectomy (OPN) was the gold standard for nephron sparing treatment of renal tumors over the last decades, even for small masses (Novick, 2004). However, in recent years continued efforts to develop techniques and skills of laparoscopic partial nephrectomy (LPN) has made it an established procedure for the treatment of small renal tumors and yields good oncological and functional outcomes, even for more complex tumors, such as hilar tumors, central tumors or tumors in solitary kidneys (Brandina and Aron, 2010). Most recently, robotic partial nephrectomy (RPN) has shown better results, by overcoming technical difficulties of LPN and providing wider degrees of freedom, tremor control and magnified vision of the surgical field (Lista et al., 2015). The expansion of renal minimally invasive procedures and the development of new surgical methods and technologies require extensive laboratory experiments in animal models before clinical use (Kerbl et al., 2011). Different animals have been used as experimental models for nephron-sparing surgery, but most experiments are performed in pig kidneys due to their anatomical similarity with the human kidney (Sampaio et al., 1998; Pereira-Sampaio et al., 2004; Bagetti Filho et al., 2007).

The collecting system suture during laparoscopic partial nephrectomy is technically challenging. It increases surgical time and consequently, renal ischemia (Zorn et al., 2007). Several studies have been carried out to simplify and accelerate this step (Hacker et al., 2007; Shikanov et al., 2009; Schatloff et al., 2014.). Previous studies on partial nephrectomy without closure have demonstrated that the pig kidney collecting system heals different from humans, without fistula or urinoma (Ames et al., 2005; De Souza et al., 2011). Recently, a study in sheep demonstrated that partial nephrectomy without closure of the collecting system resulted in urinary leakage and urinoma (De Souza et al., 2015). Thus, sheep could be a more suitable model than pigs for studies on kidney collecting system healing.

Parenchyma bleeding and urinary leakage are the most common complications in partial nephrectomies. These technical challenges must be overcome, regardless of the technique (Ramani et al., 2005; Lista et al., 2015). Detailed knowledge of renal anatomy is necessary to optimize surgical techniques, thus minimizing perioperative and postoperative complications (Klatte et al., 2015). The anatomical knowledge of intrarenal vessels is of utmost importance to perform the nephron sparing surgery with minimal complications, such as blood loss and damage to the adjacent parenchyma (Novick, 2004). The detailed intrarenal arterial anatomy has already been studied in humans (Graves, 1954; Sampaio and Aragão, 1990; Sampaio, 1992; Favorito et al., 2011; Favorito and Sampaio, 2013). Although previous studies have been published on the arterial anatomy of some animal models such as pigs (Evan et al., 1996; Pereira-Sampaio et al., 2004, 2007, 2012), dogs (Maques-Sampaio et al., 2007) and rabbits (Shalgum et al., 2011), no detailed morphological study of the sheep kidney was found. Such a study may play an important role in the continued efforts to develop the noninvasive renal treatments. The aim of this study was to describe the intrarenal anatomy (collecting system and arteries) of the sheep and compare it to previous findings in humans.

MATERIALS AND METHODS

Forty two kidneys, showing no signs of renal pathology, were collected during slaughter from 21 adult mixed breed Santa Inês and Dorper farm sheep. Ages ranged from 4 to 7 months and weight from 30 to 50 kg. The Ethics Committee on Animal Use from Fluminense Federal University approved the research protocol.

The intrarenal anatomy was studied using three-dimensional endocasts of the collecting system together with the intrarenal arteries. The endocasts were prepared using previously described techniques (Sampaio and Aragão, 1990). Briefly, the ureter and renal artery were dissected, cannulated, and injected, respectively with a yellow and red polyester resin, in order to fill the kidney collecting system and the intrarenal arterial tree. Three per cent catalyst (methyl ethyl peroxide) was added to the resin. After 24 hr to allow the resin to harden, the perirenal tissues were removed, and the renal parenchyma was digested in sequential baths of 50% concentrated commercial hydrochloric acid. Four renal casts, two right and two left, were not used because they broke. Casts from 38 kidneys were analyzed (17 pairs, 2 right, and 2 left). The collecting system morphology and the number of recesses of the renal pelvis in the sheep kidneys were observed and recorded. The branching pattern of the renal artery and branch relationship to the collecting system was recorded. Left and right data were evaluated for significant differences. Results of the sheep kidney anatomy were compared with previous findings from human, pig, dog and rabbit kidneys to estimate how useful the sheep kidney could be as a model for urologic procedures. Student's t test was used and the statistical analysis was made in the GraphPad Prism 5 for Windows software.

RESULTS

Only 38 kidneys (17 pairs, 2 lefts, and 2 rights) were adequately filled. The casts of the renal collecting system demonstrated a renal pelvis with several recesses. Recesses were observed on both dorsal and ventral surfaces of the collecting system, varying from 11 to 19 (mean of 16) in each kidney. The frequency of the number of recesses of the renal pelvis is listed in Table 1. No statistical difference was found between the number of pelvic recesses in left and right kidneys, or associated with the dorsal and ventral surfaces of the same kidney. Two animals (2/17, 11.76%) showed the same number of recesses in the left and right kidneys. There was the same number of recesses on both dorsal and ventral surfaces of the same kidney in 11 cases (28.95%). However, there were more recesses on the ventral surface than on the dorsal surface in 16 casts (42.11%), while in 12 kidneys (31.58%) there were more recesses on the dorsal surface than on the ventral surface. No calices were observed in the collecting system of the sheep kidneys.

Recesses were filled by the renal medulla (pyramids). The pyramids were fused axially in the sheep and formed a single renal crest in the center (axis) of the kidney. Interlobar arteries ran along the external surface of the collecting system (pelvis) and then passed between the recesses of the renal pelvis to reach the renal cortical area (Fig. 1B).

TABLE 1. Number of recesses of renal pelvic casts of the sheep kidney

	Left kidney		Right kidney		All kidneys	
	Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral
Mean	7	8	8	8	7	8
Standard Deviation	2.84	1.75	2.79	2.6	5.5	4.16
Minimum	6	5	5	5	5	5
Maximum	9	11	9	10	9	11

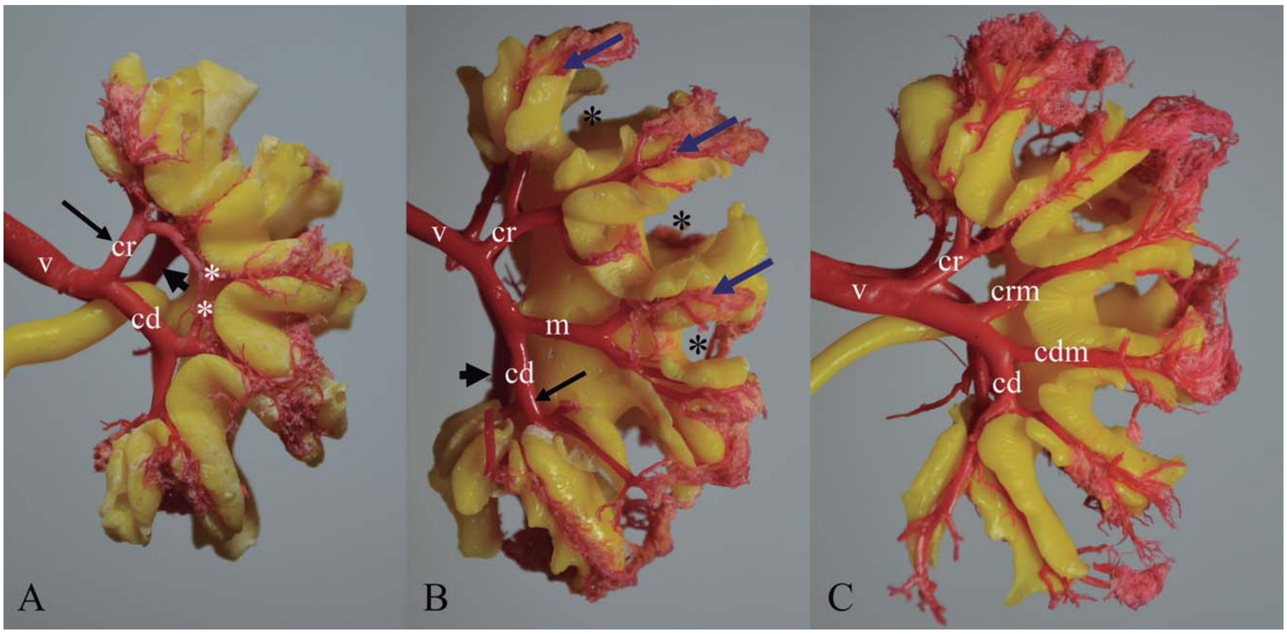

Fig. 1. Ventral view of three casts of the collecting system and intrarenal arteries of sheep. **A**. Type I—ventral branch (v) of the renal artery divided into cranial (cr) and caudal (cd) segmental arteries. Ventral mid zone is supplied by the cranial and caudal segmental arteries (*). Cranial pole is supplied by the ventral (long arrow) and dorsal (short arrow) cranial segmental arteries. **B**. Type II, ventral branch (v) of the renal artery divided into cranial (cr) middle (m) and caudal (cd) segmental arteries. Ventral mid zone is supplied only by the middle segmental artery. The caudal pole is supplied by the ventral (black long arrow) and dorsal (black short arrow) caudal segmental arteries. The interlobar arteries (blue arrows) run between the recesses of the renal pelvis (*). **C**. Type III, ventral branch (v) of the renal artery divided into cranial (cr), cranial middle (crm), caudal middle (cdm) and caudal (cd) segmental arteries. Ventral mid zone is supplied by the cranial middle and caudal middle segmental arteries.

In the 38 endocasts, the renal artery was singular and divided into dorsal and ventral primary branches. Both dorsal and ventral branches of the renal artery gave different segmental branches that ran along the dorsal and ventral surface of the renal pelvis and passed into the space between the recesses of the renal pelvis as interlobar arteries, in route to the renal cortex (Fig. 1B).

Dorsal and ventral primary branches of the renal artery were classified as type I, II and III according to the branching pattern of the segmental arteries on the dorsal and ventral surfaces of the collecting system. Type I had two segmental arteries, one to the cranial pole and another to the caudal pole of the kidney (Fig. 1A). Type II had three segmental arteries, one to the cranial pole, one to the mid zone and one to the caudal pole of the kidney (Fig. 1B). Four segmental arteries were found in Type III (Fig. 1C), one to the cranial pole, one to the cranial mid zone, one to the caudal mid zone and one to the caudal pole. Type I was the most frequent arterial segmentation for both dorsal (57.90%) and ventral (60.52%) branches of the renal artery (Table 2).

Concerning the dorsal and ventral branches, there was a symmetrical arterial branching pattern in 13 (34.21%) casts of the 38 kidneys, 9 (23.68%) of type I and 4 (10.53%) of type II. There was no symmetry in kidneys of type III. Regarding left and right casts, only 2 pairs had symmetry of the dorsal and ventral branches of type I (11.76%) of the 17 pairs.

The cranial pole was supplied by two segmental arteries. These vessels, one ventral and one dorsal were present in all casts and originated from the cranial segmental arteries from both dorsal and ventral branches of the renal artery. Interlobar arteries originated from these cranial segmental arteries and coursed toward the grooves between the recesses of the renal pelvis to reach the cortex (Fig. 1A). In 28 of 38 casts (73.68%), only the cranial segmental arteries from both dorsal and ventral branches of the renal artery supplied the cranial pole. In

TABLE 2. Frequency of branching pattern types of dorsal and ventral branches of the renal artery in sheep

	Type I		Type II		Type III	
	Dorsal surface	Ventral surface	Dorsal surface	Ventral surface	Dorsal surface	Ventral surface
Left kidney	26.32%	26.32%	15.78%	15.78%	7.90%	7.90%
Right kidney	31.58%	34.20%	15.78%	7.90%	2.64%	7.90%
All kidneys	57.90%	60.52%	31.56%	23.68%	10.54%	15.80%

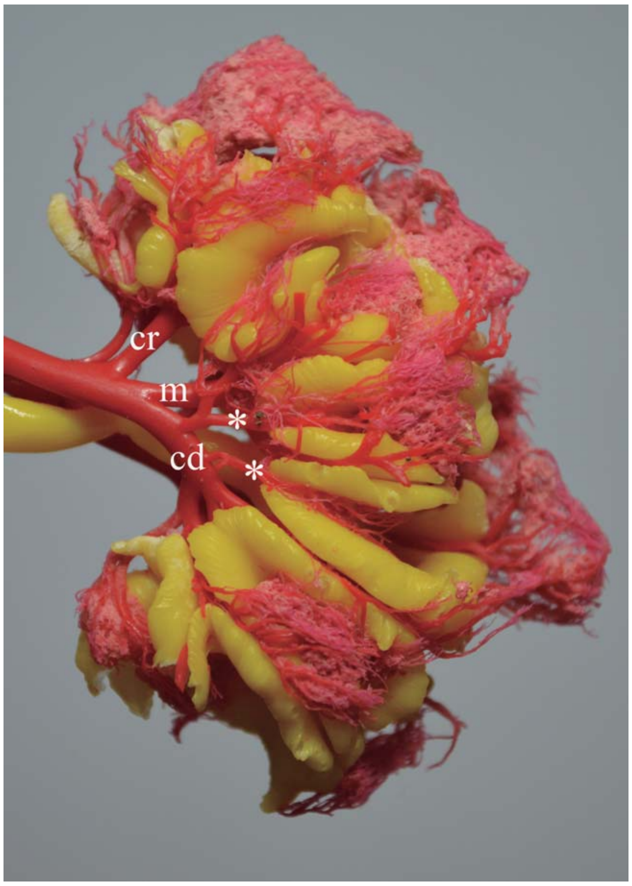

Fig. 2. Dorsal view of a cast type II, collecting system and intrarenal arteries of sheep. Showing the dorsal mid zone irrigated only by branches (*) from the caudal segmental artery (cd). The cranial pole is supplied by the cranial (cr) and the middle (m) segmental arteries.

six other casts (15.79%) the cranial middle and the caudal middle segmental arteries also gave branches to the cranial pole, and in the four remaining casts (10.56%) branches of the middle segmental artery also supplied the cranial pole (Fig. 2).

In 21 cases (55.26%) there was an apical artery running in the medial margin of the kidney toward the extremity of the cranial pole (Fig. 3). Usually, this artery arose from the dorsal branch of the renal artery (61.91%), but it also arose from the ventral branch of the renal artery (38.10%).

The most important artery of the dorsal mid zone of the kidney was the caudal segmental artery from the dorsal branch of the renal artery, which supplied this entire region in 16 casts (42.10%) (Fig. 2). Nevertheless,

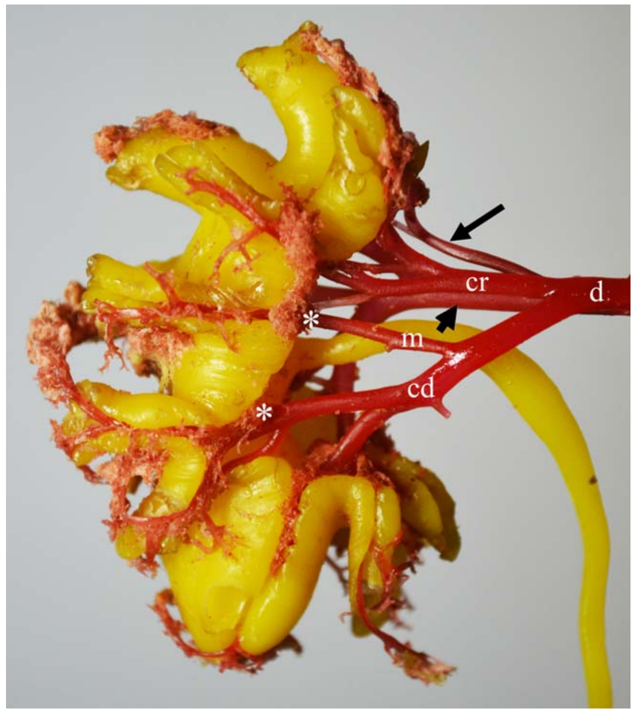

Fig. 3. Dorsal view of a cast type II, collecting system and intrarenal arteries of sheep. Showing the dorsal mid zone supplied by branches (*) from the middle (m) and caudal (cd) segmental arteries. The apical artery (long arrow) comes off from the ventral branch of the renal artery (short arrow). d—dorsal branch of the renal artery; cr—cranial segmental artery.

the caudal segmental artery irrigated the dorsal mid zone together with the cranial segmental artery in eight casts (21.05%) or together with the middle segmental artery in another three kidneys (7.89%). Moreover, in five casts (13.16%), only the middle segmental artery supplied the dorsal mid zone. In four kidneys (10.53%), the dorsal mid zone was irrigated by both the middle and cranial segmental arteries, and in the remaining two casts (5.26%) only the caudal middle segmental arteries supplied the dorsal mid zone. Therefore, the dorsal mid zone was supplied by interlobar branches from the caudal segmental artery of the dorsal branch of the renal artery in 27 of the 38 casts (71.05%), while interlobar branches from the middle segmental artery of the dorsal branch of the renal artery irrigated the region in 17 casts (31.58%) and interlobar branches from the cranial segmental artery of the dorsal branch of the renal artery supplied the dorsal mid zone in 12 casts (31.58%).

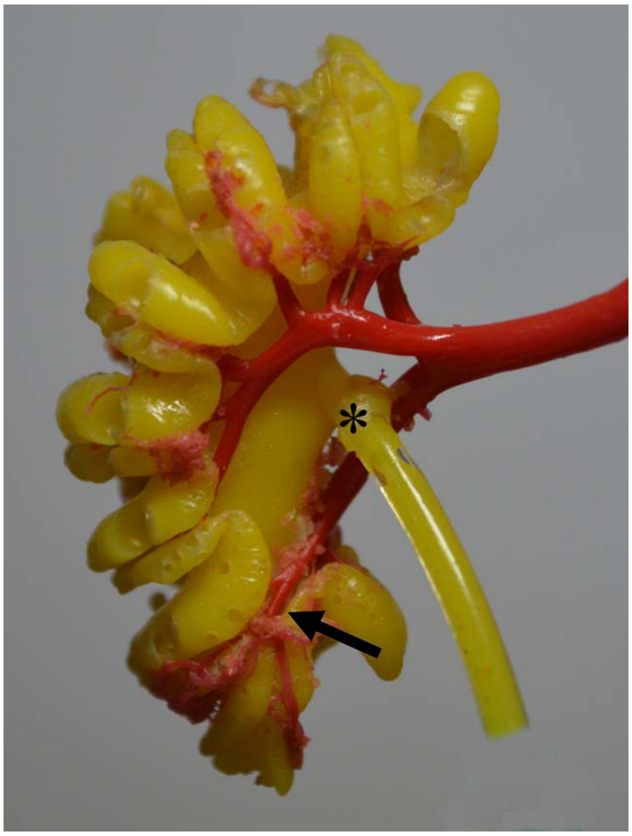

Fig. 4. Dorsal view of a cast type III, collecting system and intrarenal arteries of sheep. Showing the dorsal region of the ureteropelvic junction with no arteries (*). Caudal segmental artery from the ventral branch of renal artery is supplying the dorsal surface of the caudal pole (arrow).

The arterial supply related to the ventral mid zone of the kidney came from the interlobar branches only from the caudal segmental artery of the ventral branch of the renal artery in 16 casts (42.10%). However, the caudal segmental artery irrigated the ventral mid zone together with the cranial segmental artery in seven casts (18.42%) (Fig. 1A), or together with the middle segmental artery in two kidneys (5.26%), or together with the caudal middle segmental artery in the other two kidneys (5.26%). Moreover, in seven casts (18.42%) (Fig. 1B), only the middle segmental artery supplied the ventral mid zone. In the remaining four kidneys (10.53%) (Fig. 1C), the ventral mid zone was irrigated by the cranial middle and caudal middle segmental arteries together. Therefore, the ventral mid zone was supplied by interlobar branches from the caudal segmental artery of the ventral branch of the renal artery in 27 of the 38 casts (71.05%), while interlobar branches from the middle and cranial segmental arteries of the ventral branch of the renal artery irrigated the region in nine casts (23.68%) and seven casts (18.42%), respectively.

The caudal segmental arteries from both dorsal and ventral branches of the renal artery were in charge of the arterial supply of the caudal pole in all casts (Fig. 1B), but in 3 of 38 casts (7.89%) the caudal segmental artery from the ventral branch of the renal artery also gave branches to the dorsal surface of the renal caudal pole (Fig. 4).

The ureteropelvic junction (UPJ) had a close relationship with an important artery in both dorsal and ventral surfaces in all casts, except in two casts, where the dorsal surface of the UPJ was free of arteries (Fig. 4).

DISCUSSION

The sheep kidney does not have a calyceal system as in human and pig kidneys (Sampaio and Mandarim-de-Lacerda, 1988; Sampaio et al., 1998). Instead, the collecting system consists only of a renal pelvis with several recesses on its edge. The recesses of the renal pelvis are expansions of the renal pelvis cavity, which involve the renal pyramids Physicians, who are familiar with the human calyceal system, may confuse the recesses of the renal pelvis with the minor calyces in urograms. The number of recesses in rabbit kidney was six on each side of the renal pelvis (Sheehan and Davis, 1959), varying from 8 to 12 (Shalgum et al., 2011). Dogs presented more recesses than rabbits, ranging from 9 to 17 (Pereira-Sampaio et al., 2009). On the other hand, the sheep kidney has only a few more recesses than dogs, ranging from 11 to 19. Because of the lack of renal calices, the sheep kidney is not an adequate model for humans if the collecting system anatomy is an important point. Nevertheless, understanding its anatomy is important because it has been demonstrated that sheep could be a better model than pig for studies on collecting system healing (De Souza et al., 2015).

Different from the rabbit kidney, where the number of pelvic recesses in the dorsal surface is greater than in the ventral surface (Shalgum et al., 2011), the sheep kidney has no difference between the number of recesses on dorsal and ventral surfaces. Because the interlobar arteries pass between the recesses, in the sheep kidney there is no difference between the number of important arteries on the dorsal and ventral surfaces. It may suggest that the renal punctures performed through either kidney surface may cause similar vascular damage.

The different morphology of the collecting system of the human kidney was previously described (Sampaio and Mandarim-de-Lacerda., 1988). Recently, it was demonstrated that the classification of the collecting system midzone in humans, based on calyceal drainage, may predict difficulties for lower pole ureteroscopy (Marroig et al., 2015). Further, it was demonstrated that dog (Pereira-Sampaio et al., 2009) and rabbit (Shalgum et al., 2011) kidney collecting system has no renal minor calices. Our results showed a similar morphology for the collecting system of the sheep, thus demonstrating that dogs, rabbits and also sheep are not suitable models for ureteroscopy or any other study where the morphology of the collecting system is the utmost important issue.

In sheep, a single renal artery was found in all cases, similar to pigs (Pereira-Sampaio et al., 2004) and rabbits (Shalgum et al., 2011), but different from dogs where double (Maques-Sampaio et al., 2007) or even triple renal arteries (Jain et al, 1985) have been reported. This finding is also different from human kidney, where multiple renal arteries are found in 27–30% of cases (Sampaio and Passos, 1992). It must be considered when using sheep for training surgical procedures in which the number of renal arteries is an important factor, as in laparoscopic nephrectomy for kidney transplant donors, since the surgeon will not find multiple renal arteries as in the human patient (Johnston et al., 2001; Oh et al., 2003).

The renal artery of sheep gives dorsal and ventral primary branches in 100% of the time, similar to dogs (Maques-Sampaio et al., 2007) and rabbits (Shalgum et al., 2011). This primary division of the renal artery is similar to humans (Sampaio and Aragão, 1990). In pigs, it has been demonstrated that the renal artery divides primarily into cranial and caudal branches in 93.4% of cases (Pereira-Sampaio et al., 2004). Studies about the proportional area of the arterial segments have demonstrated that the main arterial segment in humans is the posterior (Sampaio et al., 1993), while in pigs the main arterial segment is the cranial (Pereira-Sampaio et al., 2007). These aforementioned studies demonstrated that the primary division of the renal artery is very important to determine the arterial segmentation of the kidney. Therefore, as the primary division of the renal artery in the sheep kidney, like dogs (Maques-Sampaio et al., 2007) and rabbits (Shalgum et al, 2011), is more like the human kidney (Sampaio et al., 1993) than that of the pig kidney (Pereira-Sampaio et al, 2007), we suppose that the sheep kidney could be a better model for studies where the arterial segmentation of the kidney is the most important issue. However, our results demonstrated that the caudal segmental artery of both dorsal and ventral branches of the renal artery supplied the entire caudal pole in all cases and also contributed to the dorsal and ventral mid zone in 71% of cases. Thus, to the study of the proportional area of the arterial segments of the sheep kidney, it would be interesting to determine where it is really similar to human kidney.

The type II (cranial, middle, and caudal) and type III (cranial, cranial middle, caudal middle, and caudal) of arterial branching pattern on the ventral surface of the sheep kidney is very similar to the segmental division of the human kidney, since the anterior surface of the human kidney shows three (superior, anterior, and inferior) or four (superior, anterosuperior, anteroinferior, and inferior) segmental arteries (Sampaio and Aragão, 1990).

Two important arteries, segmental cranial dorsal and segmental cranial ventral irrigated the cranial pole of the sheep kidney in all cases and gave interlobar branches for both surfaces of the cranial pole. This relationship between the arteries and the collecting system at the cranial pole is very similar to that of human, pig, dog, and rabbit (Sampaio and Aragão, 1990; Pereira-Sampaio et al., 2004; Maques-Sampaio et al., 2007; Shalgum et al, 2011). However, the sheep does not have the retropelvic artery related to the upper infundibulum as humans. This artery, when present in humans (57% of cases), supplies the posterior region of the kidney and if injured during partial nephrectomy of the upper pole can promote important bleeding and a large damage of the remaining parenchyma (Sampaio, 1992). Consequently, the cranial pole of the sheep kidney should not be used as a model for experimental procedures in which the retropelvic artery is an important point to be considered.

In 27 kidneys (71.05%) the caudal segmental artery from the dorsal branch of the renal artery supplied the entire or part of the dorsal mid zone. This relationship between the arterial branching pattern and the collecting system is comparable to dogs where the caudal segmental artery is also the most important artery of the dorsal mid zone, present in 96% of the cases (Maques-Sampaio et al., 2007). In contrast, it is different from rabbits, where the dorsal mid zone is supplied by the middle segmental artery in 76% of cases (Shalgum et al., 2011). Moreover, it is also different from pigs and humans, where the dorsal mid zone is irrigated by the cranial segmental artery in 68% of cases (Pereira-Sampaio et al., 2004) and by the posterior segmental artery in all cases (Sampaio and Aragão, 1990), respectively.

The ventral mid zone of the sheep kidney was also mostly supplied by the caudal segmental artery from the ventral branch of the renal artery. In 27 kidneys (71.05%) the blood supply of the ventral mid zone was partial or entirely provided by the caudal segmental artery. This is similar to dogs, where the caudal segmental artery is present in the ventral mid zone irrigation in 98.9% of the cases (Maques-Sampaio et al., 2007). On the other hand, it is different from rabbits, where the ventral mid zone is supplied by the middle segmental artery in 85% of cases (Shalgum et al., 2011). Furthermore, it is also different from pigs and humans, where the dorsal mid zone is vascularized by the cranial segmental artery in 60% of cases (Pereira-Sampaio et al., 2004) and by the posterior segmental artery in all cases (Sampaio and Aragão, 1990), respectively.

The caudal pole of the sheep kidney was irrigated by interlobar branches from the caudal segmental arteries of the dorsal and ventral primary branches of the renal artery in all cases. This branching pattern related to the caudal pole is similar to findings from dogs (Maques-Sampaio et al., 2007) and rabbits (Shalgum et al., 2011), where the caudal pole is supplied by two caudal segmental arteries, one on the dorsal surface and another on the ventral surface. In pigs (84.62%) and humans (62%), the caudal pole is vascularized by single caudal and inferior segmental arteries, respectively, which divide into ventral (anterior) and dorsal (posterior) branches, sending interlobar branches on both ventral and dorsal surfaces of the caudal pole (Sampaio and Aragão, 1990; Pereira-Sampaio et al., 2004). Although the branching pattern of the intrarenal arteries into the caudal pole of the sheep kidney is quite different, the relationship between the intrarenal arteries and the collecting system in the caudal pole is similar to dogs, rabbits, pigs and humans, showing one artery on each side, which gave off the interlobar branches. Thereby, the sheep kidney can be considered a good model for urological procedures when the caudal pole arterial branching pattern is an important topic to be considered.

Despite the different anatomy of the sheep kidney collecting system, without a calyceal system, that fact does not preclude its use as a model for procedures in which the anatomy of the collecting system is not an important point. Because of its similar arterial branching pattern to the human kidney in the caudal pole, the sheep kidney could serve as an experimental model. However, the lack of a retropelvic artery discourages the use of the cranial pole in experiments in which arteries are an important aspect to be considered.

LITERATURE CITED

Ames CD, Vanlangendonck R, Morrissey K, Venkatesh R, Landman J. 2005. Evaluation of surgical models for renal collecting system closure during laparoscopic partial nephrectomy. Urology 66: 451–454.

Bagetti Filho HJ, Pereira-Sampaio MA, Favorito LA, Sampaio FJ. 2007. Pig kidney: anatomical relationships between the renal venous arrangement and the kidney collecting system. J Urol 179:1627–1630.

Brandina R, Aron M. 2010. Laparoscopic partial nephrectomy: advances since 2005. Curr Opin Urol 20:111–118.

De Souza DB, Abílio EJ, Costa WS, Sampaio MA, Sampaio FJ. 2011. Kidney healing after laparoscopic partial nephrectomy without collecting system closure in pigs. Urology 77:508.e5–509.

De Souza DB, Costa WS, Damasceno-Ferreira JA, Nascimento Júnior A, Ascoli FO, Pereira-Sampaio MA, Sampaio FJ. 2016. The sheep as a model for healing studies after partial nephrectomy. J Surg Res 200:387–391.

Evan AP, Connors BA, Lingerman JE, Blomgren P, Willis LR. 1996. Branching patterns of the renal artery of the pig. Anat Rec 246: 217–223.

Favorito LA, Brito DA, Sampaio FJ. 2011. Experimental model of upper-pole nephrectomy using human tridimensional endocasts: analysis of vascular injuries. J Endourol 25:113–118.

Favorito LA, Sampaio FJ. 2013. Experimental model of lower pole nephrectomy using human 3-dimensional endocasts: analysis of vascular injuries. Urology 82:1049–1053.

Graves FT. 1954. The anatomy of the intrarenal arteries and its application to segmental resection of the kidney. Br J Surg 42: 132–139.

Hacker A, Albadour A, Jauker W, Ziegerhofer J, Albquami N, Jeschke S, Leeb K, Janestschek G. 2007. Nephron-sparing surgery for renal tumours: acceleration and facilitation of the laparoscopic technique. Eur Urol 51:358–365.

Jain RK, Dhingra LD, Kumar S, Sharma DN. 1985. Vascularization of kidneys in dogs (Canis familiaris). Indian J Anim Sci 55:406–409.

Johnston T, Reddy K, Mastrangelo M, Lucas B, Ranjan D. 2001. Multiple renal arteries do not pose an impediment to the routine use of laparoscopic donor nephrectomy. Clin Transplant 15:62–65.

Kerbl DC, McDougall EM, Clayman RV, Mucksavage P. 2011. A history and evolution of laparoscopic nephrectomy: perspectives from the past and future directions in the surgical management of renal tumors. J Urol 185:1150–1154.

Klatte T, Ficarra V, Gratzke C, Kaouk J, Kutikov A, Macchi V, Mottrie A, Porpiglia F, Porter J, Rogers CG, Russo P, Thompson RH, Uzzo RG, Wood CG, Gill IS. 2015. A literature review of renal surgical anatomy and surgical strategies for partial nephrectomy. Eur Urol 68:980–992.

Lista G, Buffi NM, Lughezzani G, Lazzeri M, Abrate A, Mistretta A, Larcher A, Dell'Oglio P, Fossati N, Porter J, Ficarra V, Mottrie A, Guazzoni G. 2015. Margin, ischemia, and complications system to report perioperative outcomes of robotic partial nephrectomy: a European Multicenter Observational Study (EMOS project). Urology 85:589–595.

Marques-Sampaio BPS, Pereira-Sampaio MA, Henry RW, Favorito LA, Sampaio FJB. 2007. Dog kidney: anatomical relationships between intrarenal arteries and kidney collecting system. Anat Rec 290:1017–1022.

Marroig B, Favorito LA, Fortes MA, Sampaio FJ. 2015. Lower pole anatomy and mid-renal-zone classification applied to flexible ureteroscopy: experimental study using human three-dimensional endocasts. Surg Radiol Anat 37:1243–1249.

Novick AC. 2004. Laparoscopic and partial nephrectomy. Clin Cancer Res 10:6322s–6327s.

Oh HK, Hawasli A, Cousins G. 2003. Management of renal allografts with multiple arteries resulting from laparoscopic living donor nephrectomy. Clin Transplant 17:353–357.

Pereira-Sampaio MA, Favorito LA, Henry R, Sampaio FJ. 2007. Proportional analysis of pig kidney arterial segments: differences from the human kidney. J Endourol 21:784–788.

Pereira-Sampaio MA, Favorito LA, Sampaio FJB. 2004. Pig kidney: anatomical relationships between the intrarenal arteries and the kidney collecting system. Applied study for urological research and surgical training. J Urol 172:2077–2081.

Pereira-Sampaio MA, Henry RW, Favorito LA, Sampaio FJ. 2012. Cranial pole nephrectomy in the pig model: anatomic analysis of arterial injuries in tridimensional endocasts. J Endourol 26:716–721.

Pereira-Sampaio MA, Marques-Sampaio BPS, Henry RW, Favorito LA, Sampaio FJB. 2009. The dog kidney as experimental model in endourology: anatomic contribution. J Endourol 23:989–993.

Ramani AP, Desai MM, Steinberg AP, Ng CS, Abreu SC, Kaouk JH, Finelli A, Novick AC, Gill IS. 2005. Complications of laparoscopic partial nephrectomy in 200 cases. J Urol 173:42–47.

Sampaio FJ. 1992. Anatomical background for nephron-sparing surgery in renal cell carcinoma. J Urol 147:999–1005.

Sampaio FJ, Schiavini JL, Favorito LA. 1993. Proportional analysis of the kidney arterial segments. Urol Res 21:371–374.

Sampaio FJ, Aragão AH. 1990. Anatomical reletionships between the intrarenal arteries and the kidney collectiong system. J Urol 143:679–681.

Sampaio FJB, Mandarim-de-Lacerda CA. 1988. 3-Dimensional and radiological pelviocaliceal anatomy for endourology. J Urol 140: 1352–1355.

Sampaio FJ, Passos MA. 1992. Renal arteries: anatomic study for surgical and radiological practice. Surg Radiol Anat 14:113–117.

Sampaio FJ, Pereira-Sampaio MA, Favorito LA. 1998. The pig kidney as an endourologic model: anatomic contribution. J Endourol 12:45–50.

Schatloff O, Nadu A, Lindner U, Ramon J. 2014. Simplifying laparoscopic nephrectomy: the inferior approach with en bloc stapling of the renal hilum. JSLS 18:e2014.00029 pii.

Shalgum A, Marques-Sampaio BPS, Dafalla A, Pereira-Sampaio MA. 2011. Anatomical relationship between the collecting system and the intrarenal arteries in the rabbit: contribution as an experimental model. Anat Histol Embryol 41:130–138.

Sheehan HL, Davis JC. 1959. Anatomy of the pelvis in the rabbit kidney. J Anat 93:499–502.

Shikanov S, Wille M, Large M, Lifshitz DA, Zorn KC, Shalhav AL, Eggener SE. 2009. Knotless closure of the collecting system and renal parenchyma with a novel barbed suture during laparoscopic porcine partial nephrectomy. J Endourol 23:1157–1160.

Zorn KC, Gong EM, Orvieto MA, Gofrit ON, Mikhail AA, Shalhav AL. 2007. Impact of collecting system repair during laparoscopic partial nephrectomy. J Endourl 27:315–320.