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Anatomy of renal veins in swine

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Summary

Swine organs are the best animal model for urological experiments. The aim of the study was to evaluate the course and size of renal veins in swine. Such knowledge is important to both human and veterinary medicine. The study was conducted on 94 kidneys, 47 right and 47 left ones, taken from adult domestic swine (Sus scrofa domestica). The kidneys were dissected and corrosion casts were made. The average length of the left renal vein was 50.92 mm, while the length of the right renal vein was on average 30.13 mm. The lumen diameter was on average 10.94 mm. The average cross-sectional area of renal veins was 100 mm^2. A renal vein most often arises from the anastomosis of two tributaries, and is usually formed outside the kidney. Right renal veins are more than half the length of left renal veins. A renal vein has a greater mean cross-sectional area than its individual direct tributaries. An additional renal vein in swine occurs rarely. From the anatomical point of view, renal veins of swine are similar to the equivalent vessels in human kidneys. Therefore, swine kidneys can be used as organs for experimental and training purposes.

Keywords. swine, kidney, veins

The domestic swine is increasingly often used as an experimental animal. Internal organs in swine (mostly the heart and kidneys) are similar to human organs in terms of their size and build. Moreover, these organs are easy to obtain. Physiological similarities between the two species are pointed out by various authors (20). Surgical techniques, both the newly introduced and the improved ones, can be tested on animal models before they are applied in humans. Swine organs can also serve as models in education, training and renal surgeries (2, 20). Therefore, it is crucial to have a thorough knowledge of their features, which are both similar to and different from those of human organs. The swine is an important subject in research on xenotransplantation (26), i.e. transplanting animal organs to human recipients. Although this animal species cannot be an organ donor yet, the rapid development of xenotransplantation may in the future save human lives.

The aim of the study was to evaluate the course and size of renal veins in a swine. Such knowledge is seen as highly important to both human and veterinary medicine. Research was performed on the structure of vessels in swine. The results of this research were compared with results obtained in studies on the venous vascularisation of human kidneys. The knowledge of the course of veins in swine and the venous vascularisation of human kidneys will allow researchers to compare these organs and examine the differences between human and porcine organs.

Material and methods

The study was carried out on 94 kidneys, 47 right and 47 left ones, taken from adult male and female domestic swine (S*us scrofa domestica*) of the Great Polish White breed. The kidneys were taken directly after the slaughter of the animals. The organ donors weighed 70-110 kg and were 12-18 months old.

For the purpose of the research, the kidneys were dissected and corrosion casts were made. First, a renal vein was isolated, and then a cannula was inserted into the lumen of the vein. A chemohardenable material, Plastogen G, stained in blue with pigment for acrylic paint, was injected into the ligated renal vein through the cannula. Before injection, Plastogen G was diluted with methacrylate diluent to a consistency required to penetrate all structures. When the veins had been filled with the material, the organ was immersed in 0.9% sodium chloride for 24 hours at a temperature of 40ºC to make Plastogen G harden. After that, preparations were corroded in 10% potassium hydroxide in a laboratory incubator. The corrosion casts of renal veins obtained this way were then rinsed with tap water and dried. Measurements were taken with a digital slide calliper to an accuracy of 0.01 mm. Photographs were taken with a digital camera.

Results and discussion

Intermediate veins anastomosing with each other form renal veins. Depending on the way of formation and the place of opening, intermediate veins can be primary or secondary. Secondary intermediate veins result from a venous anastomosis of primary intermediate veins. Primary intermediate veins are divided into primary intermediate veins running directly into renal veins (A type) and primary intermediate veins running into secondary intermediate veins (B type) (Figures 1, 2). A renal vein was most frequently formed by the anastomosis of 2 primary intermediate veins (32 kidneys – 34.04% of cases) or of 1 primary intermediate vein and 1 secondary intermediate vein (27 kidneys – 28.72% of cases). In other cases, a renal vein was formed by the anastomosis of 3 primary intermediate veins (13 kidneys – 13.83%), 2 secondary intermediate veins (12 kidneys – 12.77%), 2 primary intermediate veins and 1 secondary intermediate vein (4 kidneys – 4.26%). Least frequently, a renal vein was created as a result of the anastomosis of the following veins: a) 2 secondary intermediate veins with 1 primary intermediate vein (2 kidneys – 2.13% of cases); b) 3 secondary intermediate veins (2 kidneys – 2.13% of cases); c) 3 primary intermediate veins with 1 secondary intermediate vein (1 kidney – 1.06% of cases); d) 4 primary intermediate veins (1 kidney – 1.06% of cases). It can be concluded that renal veins usually arose from the anastomosis of 2 intermediate veins only (71 kidneys – 75.53%), less frequently – of 3 intermediate veins (21 kidneys – 22.34%), and least frequently – of 4 intermediate veins (2 kidneys – 2.12% of cases).

The right renal veins were on average 40.83% shorter than the left renal veins. The length of the left renal veins ranged from 28.6 to 74.6 mm (on average 50.92 mm), while the length of the right renal veins ranged from 13.6 to 55.3 mm (on average 30.13 mm). The lumen diameter varied from 4.5 to 19.3 mm (on average 10.94 mm).

The average cross-sectional area ($S = \pi r^2$) was 100 mm^2 for the renal veins and 53.04 mm^2 for the secondary intermediate veins. In the primary intermediate veins joining a renal vein (A type), it amounted to 38.49 mm^2, and in the primary intermediate veins joining the intermediate secondary veins (B type), it was 19.39 mm^2. It should be mentioned that the renal veins had a greater mean cross-sectional area than their individual direct tributaries: the intermediate secondary veins and the primary intermediate veins of type A. However, the renal veins arose from the anastomosis of at least two vessels. Therefore, when considering the potential blood flow, the average cross-sectional areas of renal vein tributaries must be summed up. The number of tributaries of a renal vein and their diameter are very important for the blood flow. In 41 cases, the sum of the cross-sectional areas of the main tributaries of a renal vein was lower than the average cross-sectional area of the renal vein. In 53 cases, the average sum of the cross-sectional areas of the intermediate veins was higher than the average cross-sectional area of the renal vein (Tab. 1). It can be concluded that in the former 41 cases, the renal vein, with its cross-sectional area greater than that of its tributaries, had an inhibiting effect on the general flow of blood from the kidney to the caudal vena cava. However, in the other 53 cases, blood accelerated on the way to the caudal vena cava, flowing through the renal vein of a smaller cross-sectional area than its tributaries.

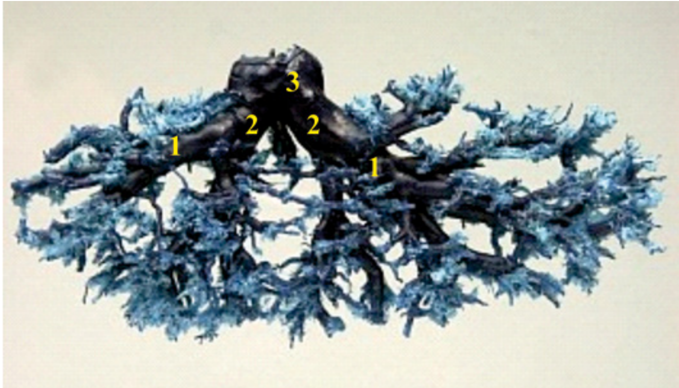

Fig. 1. Types of tributaries of a renal vein. 1 – primary intermediate veins of type B, 2 – secondary intermediate veins, 3 – renal vein. Corrosion cast, Plastogen G, Reduction: about 1.5 ×

Fig. 2. Types of tributaries of a renal vein. 1 – primary intermediate veins of type A, 2 – renal vein. Corrosion cast, Plastogen G, Reduction: about 1.5 ×

In the material examined, the place where the renal vein was formed should also be noted. A renal vein can be formed in the hilum (hilar type), in the renal sinus (intrarenal type) or outside the sinus (extrarenal type). Observations were conducted on 47 pairs of kidneys. In the organs examined, renal veins were most frequently formed outside the kidney (24 cases) and less frequently in the hilum (14 cases). Least frequently, renal veins were formed inside the renal sinus (9 cases). The place of formation of a renal vein was significant for the length of intermediate veins. If a renal vein was formed outside the kidney, the intermediate veins that

Tab. 1. Number of cases in which the average cross-sectional area of a renal vein is greater or lower than the average sum of cross-sectional areas of its tributaries

Type of intermediate veins	The average cross-sectional area of a renal vein greater than the average sum of cross-sectional areas of intermediate veins (mm^2)	The average cross-sectional area of a renal vein lower than the average sum of cross-sectional areas of intermediate veins (mm^2)
2 primary intermediate veins	14	18
3 primary intermediate veins	7	6
4 primary intermediate veins	–	1
2 secondary intermediate veins	1	11
3 secondary intermediate veins	1	1
1 primary intermediate vein and 1 secondary intermediate vein	15	12
1 primary intermediate vein and 2 secondary intermediate veins	1	1
2 primary intermediate veins and 1 secondary intermediate vein	2	2
3 primary intermediate veins and 1 secondary intermediate vein	–	1
Total	41	53

form the renal vein were longer on average by 16.2 mm than the intermediate veins in the case when a renal vein was formed in the renal sinus.

The openings of renal veins to the caudal vena cava were at different levels. The opening of a left renal vein was closer to the cranial pole of the kidney (Fig. 3). Renal veins left the renal hilum on the dorsal side and in a more cranial direction in relation to the renal artery (Fig. 4).

The occurrence of an additional renal vein could be observed in two cases. In both cases, this vein constituted an extension of a primary intermediate vein and ran directly to the inferior vena cava. The mean cross-sectional diameter of the vessel amounted to 5.65 mm.

In broad outlines, the venous systems in the kidneys of swine and humans are very similar. The differences between these systems in swine and humans can be seen in a more detailed study. With regard to renal veins, there are differences in the length, diameter, and location of these vessels.

Many authors (7, 10, 12, 14, 19, 21, 28), examining human kidneys, determined the number of tributaries that formed a renal vein after anastomosing. Poisel and Sirang (14) mention 2-3 major veins, whereas Smith (28) writes of 2-4 vessels anastomosing into a renal vein. According to Kosiński (7), renal veins result from the anastomosis of 3-6 intermediate veins, and Piasecki (12) puts the number of intermediate veins at 3-5. According to Sampaio (19), a renal vein is formed by 2-5 major venous trunks combining together: in most cases they are 3 intermediate veins (53.8% of cases) or, less frequently, 2 intermediate veins (28.8% of cases). Satyapal (21) claims that, in humans, a renal vein usually arises from the anastomosis of 3-5 venous trunks (47.1% of cases) or 2 venous trunks (38.6% of cases). Mandarim-Lacerda et al. (10) describe the occurrence of 2 venous trunks in humans in 32% of cases, 3 venous trunks in 36% of cases, and 4 venous trunks in 32% of cases. Renal veins in swine investigated in the present study were formed by the anastomosis of 2-4 venous trunks (intermediate veins). Most often, a renal vein was formed as a result of the anastomosis of 2 intermediate veins only (75.53%), less frequently, as a result of 3 intermediate veins combining together (22.34%), and least frequently, as a result of the anastomosis of 4 intermediate veins (2.12% of cases). According to Bagetti Filho (2), renal veins in swine are formed by 2 trunks (88.53% of cases) or 3 trunks (11.47% of cases). Vodenicharov and Gulubova (32) obtained similar results in a study of venous vessels in swine kidneys. They write of 2 venous trunks, cranial and caudal (*v. renalis cranialis* and *v. renalis caudalis*), forming renal veins in 75% of cases, and

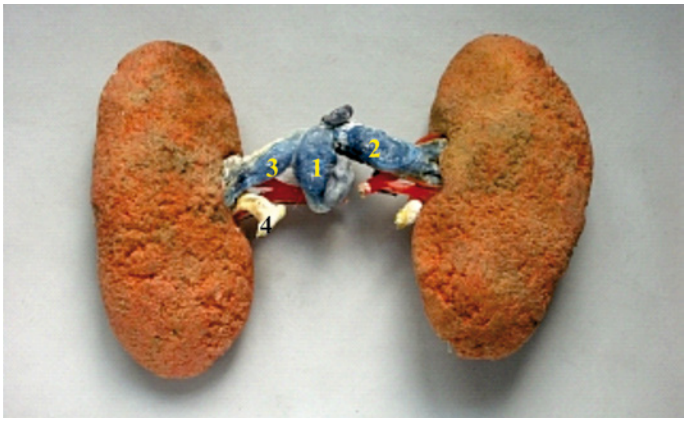

Fig. 3. The openings of the renal veins into the caudal vena cava. Ventral side: 1 – caudal vena cava, 2 – left renal vein, 3 – right renal vein, 4 – ureter. Corrosion cast, Plastogen G, Reduction: about 2 ×

Fig. 4. Location of major structures in the renal hilum. 1 – renal vein, 2 – renal artery, 3 – ureter. Corrosion cast, Plastogen G, Reduction: about 1.5 ×

an additional trunk of an intermediate vein (*v. renalis intermedia*) in only 25% of cases. The venous trunks mentioned by Vodenicharov can be compared to the secondary intermediate veins examined in the present study. Thus it can be concluded that renal veins usually arise from the anastomosis of a greater number of intermediate veins in humans (2-6 main tributaries) (7, 10, 12, 14, 19, 21, 28) than in swine (2-4 tributaries) (2, 32). In addition, research material on the swine kidney suggests that renal veins in this animal are mostly formed by only two vessels combining together. It is also worth mentioning that the main tributaries of a renal vein, which unite to form this vein, run in the horizontal plane. A similar course of these vessels in swine kidneys was also noted by Vodenicharov (32).

The length of renal veins in human material, according to Kosiński (7), is 54-92 mm for the left renal vein and 22-45 mm for the right one. According to Piasecki (12), the left renal vein is 70-90 mm long, while the right one is 20-40 mm long. Anson and Daseler (1) obtained similar results. They determined the length of the left renal vein in the range of 60-110 mm (on average 84 mm), whereas the length of the right renal vein ranged from 20 to 45 mm (on average 32 mm). Thus, the left renal vein was, on average, over two and a half times as long as the right renal vein. According to Urban et al. (30) and Kawamoto et al. (6), the left renal vein is three times as long as the right renal vein. The results obtained by these authors are as follows: from 60 to 100 mm (Urban) and 75 cm (Kawamoto) for the left renal vein, and from 20 to 40 mm (Urban) and 25 cm (Kawamoto) for the right renal vein. A large difference in the length of the opposite renal veins in humans is also noted by Satyapal et al. (22, 24). According to these authors, the left renal vein, with a length of 29-104 mm (on average 59 mm), is 2.5 times the length of the right renal vein, which is 7-42 mm (on average 24 mm) long. Ross et al. (15), as well as Beckmann and Abrams (3) present similar results: on average 57 mm (Ross et al.) and 68 mm (Beckmann and Abrams) for the left renal vein, and 20 mm (Ross et al.) and 26 mm (Beckmann and Abrams) for the right renal vein. The results of research carried out by Le Floch-Prigent (8) show that the left renal vein in humans is more than twice as long as the right one. These results stand in sharp contrast to the results obtained by Pinto (13), according to whom, the right renal vein in humans is, on average, only 13.7% shorter than the left renal vein. In swine kidneys examined in this research, the difference in length between the opposite renal veins was not as significant as in humans (1, 3, 7, 12, 15, 24, 30) (Pinto's research is an exception (13)). The length of the left renal vein ranged from 28.6 to 73.85 mm (on average 50.92 mm), and the length of the right renal vein from 13.6 to 55.3 mm (on average 30.13 mm), which means that the right renal veins were more than half the length of the left renal veins. The right renal veins were, on average, 40.83% shorter than the left renal veins. Similar results on the length of renal veins in swine were presented by Vodenicharov (31): the left renal veins were only slightly longer than the right renal veins (on average 28.45 mm and 24.52 mm long, respectively). Thus, in the animal material studied by Vodenicharov, the right renal veins were also more than half the length of the left renal veins. This stands in clear contrast to the results obtained in studies of human kidneys (except those by Pinto).

In addition to the above-mentioned differences, the average length of the left renal veins in swine is smaller than the average length of the left renal veins in humans. It results from the fact that the extrarenal formation (thus closer to the caudal vena cava) of porcine renal veins occurs more often. The length of the right renal vein in both species is approximately the same.

The diameters of renal veins in humans, according to Kosiński (7), range from 5 to 14 mm, and according to Piasecki (12), from 12 to 16 mm, whilst according to Le Floch-Prigent (8), they range from 12.8 to 16.1 mm. In a study by Satyapal et al. (22, 24), the diameter of the left renal vein ranges from 7 to 16 mm (on average 12 mm), and the diameter of the right renal vein from 7 to 17 mm (on average 12 mm). According to Lemańska and Wójtowicz (9), the diameter of a renal vein in humans amounts to 15.6 mm. In swine, these dimensions are within the range of 4.5 to 15.8 mm (mean 10.94 mm). According to Vodenicharov (31), the diameters of renal veins in swine are 8.14 mm for the left renal vein, and 8.17 mm for the right one. It can be noticed that the mean diameter of renal veins in swine is slightly smaller than it is in humans.

Kosiński (7), in a study based on 118 human kidneys, reports 17 cases where the formation of renal veins was intrarenal, 77 cases where renal veins were formed in the hilum, and 24 cases where they was formed outside the kidney. Thus, renal veins in humans are formed mostly in the hilum of the kidney. In the porcine kidney, it is quite the opposite. The intrarenal formation of renal veins in swine was observed in 9 out of 47 kidneys examined. The formation in the hilum occurred in 14 cases, and the extrarenal formation in 24 cases. It is clear that renal veins in swine kidneys usually arise outside the organ, less frequenly in the hilum. It is probably related to the size of the pelvicalyceal collecting system, which is definitely larger in swine than in humans (29). The pelvicalyceal collecting system, occupying most of the hilum of the swine kidney, may be the cause of renal veins forming usually outside the organ.

Additional renal veins are less common in animal kidneys. Many authors have written about additional renal veins in human kidneys. Almost all of the authors (except Sido (25)) report that additional renal veins are present in 9% to over 33% of human kidneys (6, 7, 15, 21, 23, 30), that is, much more often than in porcine kidneys. In the animal material examined in the present study, additional renal veins occurred in 2 cases only

(2.13%). The mean cross-sectional diameter of the lumen of this vessel is smaller in swine than in humans. It amounts to 5.65 mm for swine, and to 13 mm (4) or 7-9 mm (22) for humans.

Similarly as in the material examined here, studies performed on swine kidneys by Bagetti Filho (2) show that the main tributaries of renal veins, i.e. intermediate veins, occur on the ventral side in relation to the renal pelvis. Bagetti Filho reports that a small percentage (3.28%) of large venous trunks running on the dorsal side of the renal pelvis open directly into renal veins. These results concur with those obtained by Sleight and et al. (27) and Piasecki (12). Sampaio (19) presents slightly different results. He claims that on the rear side of the pelvicalyceal collecting system in humans, a vessel can occur (in 69.2% of cases) that has a larger diameter and runs directly into a renal vein or even the inferior vena cava. Hollinshead (5) claims that, in the sinus, renal veins usually run on the ventral side of the renal pelvis. However, he adds after Merklin and Michels (11) that in 30% of cases, large tributaries of renal veins run on the dorsal side of the pelvis. Large dorsal tributaries of renal veins in humans are also described by Sampaio (16-19). In swine, all tributaries of renal veins run on the dorsal side. On the basis of these data, it can be concluded that the renal pelvis in the swine kidney is much more accessible than in the human kidney. Inserting a needle into the renal pelvis of a swine from the dorsal side poses a lower risk of damage to a larger venous trunk than it does in humans.

Urban et al. (30) describe the location of the main renal vessels in the renal sinus. These authors describe the front course of renal veins in relation to the renal artery. The same course of these vessels can be observed in the animal material investigated in the present study. In all cases, renal veins ran in the renal sinus, ventrally in relation to the homonymous artery.

Conclusions:

1. A renal vein most often arises from the anastomosis of 2 tributaries, less frequently of 3 tributaries, and least often of 4 tributaries.

2. Right renal veins are over half the length of left renal veins.

3. Renal veins have a greater mean cross-sectional area than their individual direct tributaries.

4. Renal veins in swine are usually formed outside the kidney, less frequently in the hilum, and least frequently inside the kidney.

5. Additional renal veins in swine occur rarely.

6. There are slight differences in length, diameter, and number of tributaries between the renal veins of porcine kidneys and those of human kidneys. However, there are also similarities. From the anatomical point of view, the renal veins of swine are very similar to the equivalent vessels in human kidneys in terms of their course, place of opening, and types of veins that form renal veins. Therefore, swine kidneys can be used as organs for experimental and training purposes.

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