Macroscopic distribution of the renal artery and intrarenal arteries in mole rats (*Spalax leucodon*)

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ABSTRACT: A study was conducted of the kidneys of adult mole rats (*Spalax leucodon*) to describe the macro- and mesoscopic morphology of the renal arterial distribution and some additional anatomical features. The kidneys of the mole rat lay alongside the vertebral column in the abdominal region, the right kidney situated more cranial than the left. Covered by a thin connective tissue capsule, the kidney was bean-shaped, smooth, and reddish-brown. The mean live weight of the studied mole rats was 203.6 ± 15.05 g. The mean kidney weight was 0.636 ± 0.048 g. The mean weight of the right kidney (0.641± 0.039 g) was significantly ($P < 0.01$) heavier than that of the left one (0.630 ± 0.057g). Sixteen three-dimensional endocasts of the renal artery and intrarenal arteries were prepared using standard injection-corrosion techniques and examined. A single renal artery was observed in 100% of the specimens. The renal arteries divided, forming a dorsal and a ventral branch; these bifurcated forming cranial and caudal segmental branches. No anastomoses were observed between any of these branches.

Keywords: anatomy; kidney; endocast; renal arteries; mole rat (*Spalax leucodon*)

Rodents constitute the most diverse and numerous order of mammals living today. There are 29 families, 426 extant genera, and 1814 extant known species of rodents (Nowcak 1991). They are found in a wide variety of habitats such as deserts, tundra, mountains, burrows, and aquatic environements. The species of Spalax belong to a family (Spalacidae) of subterranean rodents of the Muroidea superfamily, prevalent in the Middle East, Eastern Mediterranean and North Africa. Spalacidae emerged during the Oligocene period (30–40 million years ago) in what is now Anatolia, and spread throughout Anatolia, the Balkans, the Russian steppes, the Middle East, and North Africa (Nevo 1999). The *Spalax* genus of this family inhabits an underground tunnel system that it maintains and expands throughout its life. Spalacids thrive at an altitude ranging from 300 meters in Israel to 2600 meters on Mount Nemrut in Anatolia. Eyes are undeveloped and the orbits are covered with skin. Accordingly, they are termed the blind mole rat (*Spalax leucodon*). They are also different from other rodents in that auricles are absent. The genus Spalax may be found in most regions of Turkey and is represented by two species (S*palax leucodon*, *Spalax ehrenbergi*) (Kivanc 1988).

Although *Rattus* and *Spalax* belong to similar families, their physiological and anatomical features are markedly different (Nowack 1991). Spalacids are difficult to capture due to their behavioural features since they usually live in underground galleries. They are hypoxia-tolerant (able to survive at an oxygen level of 7% in underground galleries), and they manifest morphological, physiological, and behavioural characteristics under routine conditions with high carbon dioxide levels below the ground. It has been reported that under experimental laboratory conditions, *Spalax leucodon* was able to survive for 14 h at a level of 3% oxygen, while rats died after 2–4 h at the same oxygen level. Therefore, *Spalax leucodon* is proposed as a suitable animal model for studies of hypoxia (Shams et al. 2004). In addition to its adaptations to life underground, the maximum lifespan reported for *Spalax* is 21 years (Edrey et al. 2012). By comparison, mice and rats belonging to the same superfamily have a maxi-

mum lifespan of four years (Turturro et al. 1999; De Magalhaes et al. 2005). Moreover, spontaneous tumours have never been reported in Spalacids (Gorbunova et al. 2012).

The kidney is an essential organ involved in the removal of nitrogenous substances, excess water, and the homeostatic osmotic concentration of blood. Characteristic features of the renal anatomy of various mammals (Fuller and Huelke 1973; Horacek et al. 1987; Sindel 1990; Aslan 1995; Aksoy and Ozudogru 2003; Aksoy et al. 2004; Pereira-Sampaio et al. 2004) and some morphometric parameters of kidney of rodents living in different climatic conditions (Ernest and Francis Roe 1967; Kozma et al. 1974; Akayevsky 1975; Olukole 2009; Oyeanusi et al. 2007; Oyeanusi et al. 2009) have been reported. However, no work has been carried out on the morphometric parameters of kidney and renal arteries of *Spalax leucodon*. The aim of this study was to determine and describe the branching of the renal arteries and selected morphometric features of the kidneys in *Spalax leucodon*.

MATERIAL AND METHODS

Twenty adult mole rats (nine females, 11 males), trapped by farmers, were used. Animals were anaesthetised with a combination of 10 mg/kg xylazine (Rompun® inj; Bayer Turk Kimya San. Ltd. Sti. Istanbul) and 100 mg/kg ketamine HCl (Ketalar® Eczacibasi Istanbul) intraperitoneally. Heparin (Liquemine IV, Roche Mustahzarlari San. A.S.) was administered (450 IU/20 g, *i.v.*) slowly to minimise coagulation. Subsequently, animals were euthanised by bleeding via an incision of the *aorta ascendens.* While they were in deep anaesthesia, their vessels were flushed with 0.9% physiological saline via an implanted canula. The kidneys were removed along with the renal arteries, weighed using a Mettler balance with a sensitivity of ± 0.01 g. Then, takilon (20% powder monomethyl-methacrylate and 80% liquid polymethyl-methacrylate) was injected into the renal artery. The corrosion cast method was applied to the kidneys (as originally described in Sindel et al. 1990; Yoldas and Nur 2012). After injection of takilon, the kidneys were maintained at room temperature for 24 h to allow plastic polymerisation. Finally, the kidneys were digested to reveal the casts in a solution of 30% KOH at 60 °C for 24–48 h, washed with tap water, and photographed.

Arteries were measured using digital calipers (DV892 Calipers, Tecnotest corp., Munich, Germany) with a sensitivity of 0.01% mm. All data were analysed using SPSS version 11.5. Homogeneity of data was examined using the Kolmogorov-Smirnov test and observation data were homogeneously distributed.

For terminology, the Nomina Anatomica Veterinaria was used (World Association of Veterinary Anatomists 2005).

RESULTS

The kidney of the mole rat was bean-shaped, smooth, and reddish-brown. It was covered by a thin connective tissue capsule. Each kidney revealed a dorsal and a ventral surface, a medial and a lateral aspect, and a cranial and a caudal pole. The major renal vessels and ureter had their entry or exit medially at the hilum. The kidneys lay alongside the vertebral column, protruding into the abdominal cavity and were localised retroperitoneally. While the right kidney was positioned at a level of about the 13th intercostal space and the first lumbar vertebra, the left kidney lay at a level of the first and 3rd lumbar vertebrae. The left kidney lay in proximity to the stomach, pancreas, descending colon, spleen, and small intestine; the right kidney lay in proximity to the liver.

The average live weights of the male and female mole rats were 221.3 ± 17.7 g and 185.9 ± 14.4 g, respectively (Table 1). The mean weight of the right kidney was 0.632 ± 0.012 g, and was thus heavier than the left (0.596 ± 0.022 g) (Table 2). The kidney weights were also significantly correlated ($P < 0.01$)

Table 1. Weight of the kidneys in the *Spalax leucodon* (mean ± SEM)

	Live weight (g)	Right kidney weight (g)	Left kidney weight (g)
All (n = 20)	203.6 ± 15.05	0.641 ± 0.039	0.630 ± 0.057
Male (n = 11)	221.3 ± 17.7	0.691 ± 0.043	0.683 ± 0.038
Female (n = 9)	185.9 ± 14.4	0.592 ± 0.035	0.578 ± 0.075

Table 2. Live weight, kidney weight and their ratios in the *Spalax leucodon* (mean ± SEM)

	Live weight (g)	Kidney weight (g)	Ratio of live weight to kidney weight
All (n = 20)	203.6 ± 16.05	0.636 ± 0.048	320.1 : 1
Male (n = 11)	221.3 ± 17.7	0.687 ± 0.033	322.1 : 1
Female (n = 9)	185.9 ± 14.4	0.585 ± 0.045	317.7 : 1

Table 3. Morphometric values of the renal arteries in male and female *Spalax leucodon* (mean ± SEM)

	A1	Db1	Vb1	A2	Db2	Vb2
All (n = 16)	1.10 ± 0.0287	5.300 ± 0.16	6.10 ± 0.06	0.97 ± 0.03	5.55 ± 0.18	6.05 ± 0.05
Male (n = 8)	1.28 ± .0191	5.200 ± 0.13	6.20 ± 0.13	1.10 ± 0.02	5.40 ± 0.22	6.10 ± 0.30
Female (n = 8)+	0.99 ± 0.313	5.400 ± 0.30	6.00 ± 0.2	0.91 ± 0.03	5.70 ± 0.30	6.1 ± 0.1

A1 = the length of the right renal artery from its origin to the hilum of the kidney (cm), A2 = the length of the left renal artery from its origin to the hilum of the kidney (cm), Db1, Vb1, Db2, Vb2 = the number of interlobar arteries of the dorsal and ventral branch of the right and left renal arteries, respectively

with body weights; the ratios of body weight to kidney weight in males and females were 322.1 : 1 and 317.7 : 1, respectively (Table 2).

In all animals, the right and left renal arteries emerged laterally from the abdominal aorta. The right renal artery originated from the lateral aspect of the abdominal aorta just cranial to the origin of the cranial mesenteric artery. The left renal artery arose slightly caudal to the right renal artery, from the lateral aspect of the abdominal aorta, 0.3–0.4 cm caudal to the celiac artery (Figure 1). In one animal (6.25%), the left and right renal arteries arose laterally from the abdominal aorta at the same level. After its origin, the left and right renal artery coursed caudolaterally and bifurcated as dorsal and ventral branches (primary branches) before arriving at the hilum. The length of the right renal artery arriving at the hilum was greater than the left. This length was greater in males than in females (Table 3). Each primary branch bifurcated as cranial and caudal segmental branches (secondary branches) (Figures 1 and 2). In turn, these segmental branches gave rise to 4–6 interlobar arteries (Figure 1; Table 3). There was no positive correlation found between the body weight of rats and the number of interlobar branches. Furthermore, the number of interlobar branches of renal arteries was not significantly different between males and females.

In three right and one left kidney, cranial or caudal segmental branching was not observed. In these cases, interlobar arteries diverged directly from the dorsal and ventral (primary) branches (Figure 1). Moreover, in one kidney (6.25%), the dorsal branch of the renal artery supplied an interlobar branch to the cranial pole of the kidney. In six (37.5%) right kidneys, the ventral branch of the renal artery supplied more interlobar arteries than the dorsal branch; for the left kidneys this was true in four cases (25%).

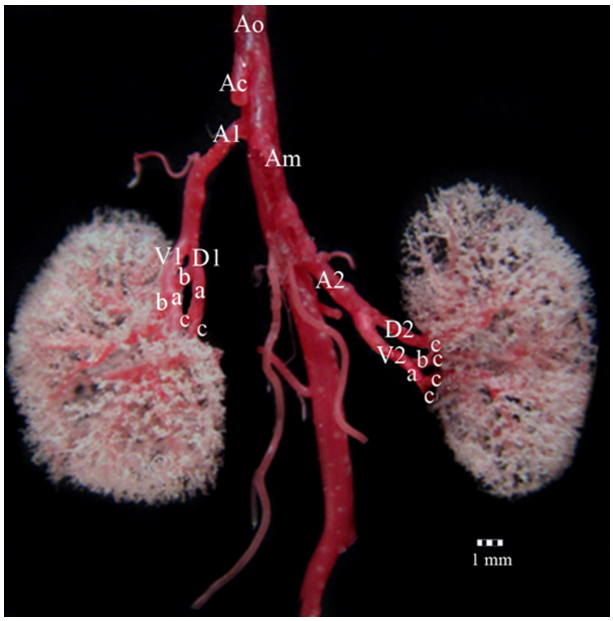

Figure 1. The origin of the renal arteries (ventral view). A1 = right renal artery, A2 = left renal artery, D1 = the dorsal branch of the right renal artery, D2 = the dorsal branch of the left renal artery, V1 = the ventral branch of the right renal artery, V2 = the ventral branch of the left renal artery, a = the caudal division of the renal artery, b = the cranial division of the renal artery, c = interlobar artery, Ao = abdominal aorta, Ac = celiac artery, Am = cranial mesenteric artery

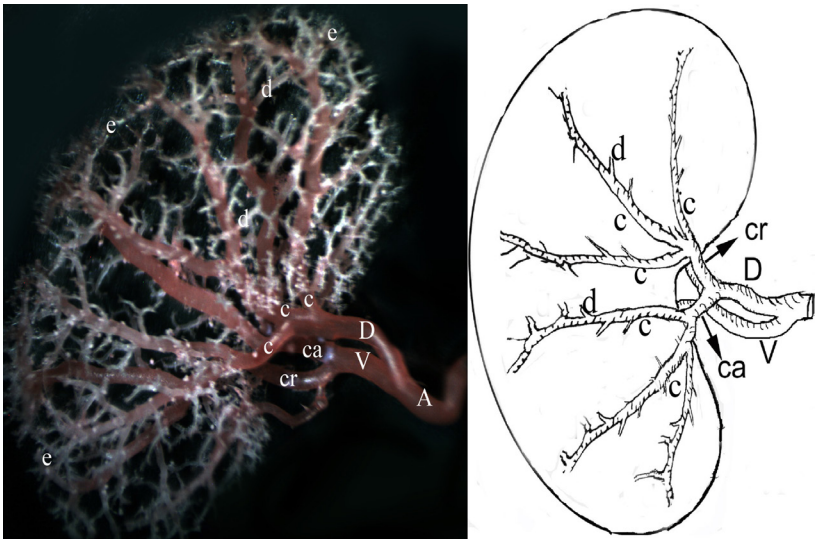

Figure 2. The intrarenal branches of the renal artery (dorsal view). A = renal artery, D = the dorsal branch of the renal artery, V = the ventral branch of the renal artery, ca = the caudal division of the dorsal branch of the renal artery, b = the cranial division of the dorsal branch of the renal artery, c = interlobar artery, d = arcuate artery, e = interlobular artery

At the cortical-medullary junction, interlobar arteries were observed to give off several arcuate arteries (Figure 2). Arcuate arteries together spread over the entire interface of the cortex and medulla. In turn, each arcuate artery gave rise to many interlobular arteries. These radiating interlobular arteries were distributed throughout the cortex (Figure 2). No anastomoses were seen macroscopically between any of the subdivisions of the renal arteries.

DISCUSSION

The shape and colour of the kidneys of the mole rats observed in this study were similar to those reported for the African giant rat (Oyeanusi et al. 2007; Oyeanusi et al. 2009), African great cane rat (Olukole 2009), and the common laboratory (Wistar) rat (Hebel and Stromberg 1976). The location and anatomical relationships of the left and right kidneys were also similar to previous reports in rodents (Kozma et al. 1974; Hebel and Stromberg 1976; Olukole 2009; Oyeanusi et al. 2007; Oyeanusi et al. 2009).

The 0.31% relative kidney weight obtained in the present study is higher than the 0.25% reported for the African giant rat (Oyeanusi et al. 2007; Oyeanusi et al. 2009), but lower than the 0.76 and 0.36% reported in the Wistar rat and African great cane rat obtained by Hebel and Stromberg (1976) and Olukole (2009), respectively. The right kidney was heavier than the left. This finding agrees with those of Akayevsky (1975), Onyeanusi et al. (2009), Ernest et al. (1967), and Kozma et al. (1974). As reported by Onyeanusi et al. (2007), Onyeanusi et al. (2009) in the African giant rat and Wistar rat, the mole rat kidneys weights were significantly correlated ($P < 0.01$) with body weights.

We found that renal arteries diverged from the lateral aspects of the abdominal aorta in 100% of samples, as reported by others (Fuller and Huelke 1973; Hebel and Stromberg 1976; Nickel et al. 1981; Satyapal et al. 2001). Although multiple renal arteries per kidney have been reported in humans (Satyapal et al. 2001) and dogs (Jain et al. 1985), in 100% of the kidneys examined here we observed only a single renal artery, as has also been reported for cats (Aksoy et al. 2004), sheep and goats (Aslan and Nazli 2001), rats (Fuller and Huelke 1973), pigs (Akayevsky 1975), and rabbits (Sindel et al. 1990; Ertas 2006). Consistent with the report of Khamanarong et al. (2004) in the dog, in one of the mole rats the right and left renal arteries arose from the aorta at the same level.

Although the left renal artery was reported to be longer than the right (Aksoy and Ozudogru 2003), some researchers have described the opposite phenomenon in some species (Aksoy et al. 2004; Ramezani et al. 2008). In all cases, the right renal artery was slightly longer than the left renal artery.

We noted that the primary divisions of renal arteries were a dorsal and a ventral branch, as also reported in most mammals (Aksoy and Ozudogru 2003; Fuller and Huelke 1973; Khamanarong et al. 2004). However, two or more branches have been reported in the dog (Christensen 1952; Khamanarong et al. 2004), while it was reported that the primary division of the pig renal artery forms a cranial and a caudal branch in 93.4% of cases (Pereira-Sampaio et al. 2004).

Similar to reports in rats (Fuller and Huelke 1973) and dogs (Khamanarong et al. 2004; Marques-Sampaio et al. 2007), we observed the dorsal and ventral branches of renal arteries to be divided as cranial and a caudal segmental arteries. Thereafter, the cranial and caudal branches of renal arteries gave off multiple interlobar arteries. However, it has been described for sheep (Aksoy et al. 2004), goats (Aslan and Nazli 2001), calves (Jain and Sing 1987), and rabbits (Sindel et al. 1990; Ertas 2006) that the dorsal and ventral branches of the renal arteries have no cranial and caudal branches, similar to some of the mole rat kidneys.

In the mole rat, at the medulla-cortex junction the interlobular arteries gave rise to arcuate arteries. Each of the arcuate arteries gave rise to many interlobular arteries, as reported for rabbits (Sindel et al. 1990; Ertas 2006), rats (Fuller and Huelke 1973), canines (Aksoy and Ozudogru 2003; Aslan 1995; Khamanarong et al. 2004; Marques-Sampaio et al. 2007), and sheep (Aslan and Nazli 2001). Aslan and Nazli (2001) and Nur and Yoldas (2011) reported an anastomosis between the dorsal and ventral branches in one kidney. We did not encounter any such finding in this study.

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