Macroscopic Features of the Arterial Supply to the Reproductive System of the Male Ostrich (*Struthio camelus*)

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Summary

The macroscopic features of the arterial supply to the reproductive system of the male ostrich was studied in 16 pre-pubertal and eight sexually mature and active birds. The left and right cranial renal arteries arise from the aorta, between the cranial divisions of the kidneys. These vessels supply the cranial divisions of the kidneys, the testes, the epididymides and the cranial segments of the ducti deferentia. Accessory testicular arteries which arise directly from the aorta are present in 45.8% of the specimens. They supply the testes and cranial parts of the ducti deferentia. They are variable in number and origin, and four variants are identified. A cranial ureterodeferential branch originates from the cranial renal artery, supplies the cranial portion of the ductus deferens and ureter, and runs caudally to anastomose with the middle renal artery. The sciatic artery arises laterally from the aorta, just caudal to the acetabulum, and gives rise, ventrally, to a common trunk, the common renal artery, which divides into the middle and caudal renal arteries. The middle renal artery gives rise to the middle ureterodeferential branch which supplies the middle part of the ductus deferens and ureter. A few centimetres caudal to

the kidney, the aorta terminates in three branches, namely, the left and right internal iliac arteries and the median caudal artery. The internal iliac artery divides into the lateral caudal artery and the pudendal artery; the latter gives off caudal ureterodeferential branches that supply the caudal segments of the ductus deferens and ureter. In addition, the pudendal artery gives off vessels that supply the cloaca, some of which continue to the base of the phallus, where they form an arterial network. In conclusion, the pattern of the blood supply to the reproductive organs of the male ostrich is, in general, similar to that of the domestic fowl and pigeon, although there are a few highlighted distinctive features.

Introduction

The ostrich industry currently forms a small but important component of the South African economy and has also become established in various other countries such as Namibia, Zimbabwe, Israel, Australia, the USA and parts of Europe (Deeming and Angel, 1996; Deeming, 1999). During recent years, the world-wide demand for ostrich products has increased (Kimminau, 1993; Deeming, 1999) which has put pressure on ostrich breeders to supply an increasing number of slaughter birds for the market.

The increasing economic importance of the ostrich as a farmed bird, coupled with pressure for accelerated production, makes it imperative to fully understand the reproductive biology of this species, particularly in view of the reported low fertility and hatchability prevalent in the industry (Deeming and Ar, 1999). While factors such as poor management, nutritional imbalances and the incorrect incubation of eggs, etc. play a role in this phenomenon, the fertility of male ostriches may also be a contributory factor. Very little information, however, is available on the basic reproductive biology of the male ostrich. Although some aspects of the structure of the male reproductive organs have been published (MacAlister, 1864; Duerden, 1912; Budras and Meier, 1981; Cho et al., 1984; Bezuidenhout, 1986, 1999; Fowler, 1991; Soley, 1992; Soley and Groenewald, 1999; Aire et al., 2003), no information is available on the vascularization of these organs.

The vascular system of the male reproductive tract in birds has, in general, been poorly studied, with only that of the domestic fowl having been described in any detail (Nishida, 1964). A general description of the arterial supply to the male reproductive organs of the domestic pigeon has also been provided (Bhaduri et al., 1957). As part of a study on the vascularization of the male reproductive tract of the ostrich, this paper describes the gross pattern of the arterial supply to the testis, epididymis, ductus deferens and phallus. The terminology used is that of Nomina Anatomica Avium (Baumel et al., 1993).

Materials and Methods

The torsos of 24 male ostriches with viscera intact, but which had been skinned and from which the limbs had been removed, were obtained from the Oryx abattoir in Krugersdorp, Gauteng and from the Klein Karoo abattoir in Oudtshoorn, Western Cape, South Africa. The specimens consisted of 16 semi-adult birds (12–14 months old) and eight sexually mature and active birds (3 years and older).

The arterial system of 18 torsos (12 semi-adult and six sexually mature birds) was flushed free of blood by injecting physiological saline through the descending aorta using a 50-ml syringe. Using the same technique, red latex (Plastomax supplies CC, Pretoria, South Africa) was subsequently injected into the arteries via the same route. Severed arteries resulting from the slaughter process and which leaked latex were closed off using artery forceps. The torsos were trimmed of excess tissue, immersion-fixed in a 10% formalin bath for a minimum period of 5 days, rinsed in running water for two days and then carefully dissected to expose the latex-filled arteries. The specimens were also utilized for a description of the morphological and topographical features of the reproductive tract.

The remaining six torsos (four semi-adult and two sexually mature birds) were rinsed with physiological saline as described above but were injected with a polyester resin (Plastomax supplies CC) via the descending aorta. The specimens were subsequently kept in a cold room (approximately 4°C) for a number of days after which the tissue was macerated in a 20–30% sodium hydroxide solution until the resin-filled arteries were exposed.

The pattern of the arterial system was described and visually recorded by using a Nikon Coolpix 4500 digital camera (Nikon Corporation, Tokyo, Japan).

Results

Basic morphological features and topography of the reproductive organs and kidneys

For proper perspective, the morphological features and topography of the reproductive organs and kidneys are briefly described. The anatomical features of the male reproductive organs and kidneys in the ostriches resembled those previously described for this bird (MacAlister, 1864; Duerden, 1912; Cho et al., 1984; Bezuidenhout, 1986, 1999; Soley, 1992; Soley and Groenewald, 1999). The reproductive organs comprised the testis, epididymis and deferent duct which opened into the urodeum of the cloaca via small papillae, as well as the phallus.

The testes were closely related topographically to the kidneys with which they shared some arteries. The kidneys displayed three divisions, namely cranial, middle and caudal. They lay immediately ventral to the synsacrum and stretched between the last vertebral rib and the middle of the pelvis. The medial aspects of the kidneys bordered the aorta which lay in the dorsal median plane. The ureters extended from the caudo-medial surfaces of the cranial division of the kidneys, and ran caudally close to the midline accompanying the ducti deferentia. They opened into the urodeum of the cloaca close to the papillae of the ducti deferentia.

The testis

The intra-abdominal testes were situated on either side of the caudal vena cava, ventral to the cranial divisions of the kidneys, and caudal to the adrenal glands. They were attached to the body-wall by a fold of mesentery and demonstrated a marked variability in size in the specimens examined.

The semi-adult birds displayed small rod-shaped testes which measured approximately 1.3–4.6-cm in length and 0.5–0.8-cm in width, while in the sexually mature birds, they were oval structures approximately 7.6–14.2-cm long and 5–7-cm wide.

The epididymis

The epididymis was attached to the dorsomedial surface of the testis and in the sexually mature birds extended several centimeters caudal to the testis (Figs 1 and 2). It was divided into three parts: the cranial appendix, the main part attached by connective tissue to the testis along most of its length, and the free caudal extremity which was continuous caudally with the ductus deferens. In semi-adult birds the epididymis was poorly developed.

The deferent duct

The ductus deferens was best identified in sexually mature and active birds. The ductus deferens left the caudal part of the epididymis, first as a fairly straight tube and then as a highly convoluted tube that ran parallel to the ureter, near the midline. Close to the cloaca, the duct became straight, forming the pars recta ductus deferentis, and subsequently expanded into a spindle or barrel-shaped structure, the receptaculum ductus deferentis that opened into the urodeum of the cloaca via the papilla of the ductus deferens.

The phallus

The phallus was attached to the ventral wall of the cloaca and exhibited the typical anatomical features summarized by Soley and Groenewald (1999). In semi-adult birds (pre-pubertal), the flaccid phallus was approximately 1.2–2-cm wide and 1.5–5.5-cm long, whereas in the sexually mature adult birds it was approximately 3–6.9-cm wide and 20–24-cm long.

Arterial Supply to the Reproductive Organs

The testis and epididymis

The testicular artery (arteria testicularis)

The testis and epididymis were supplied by the testicular artery and, in some instances, one or more accessory testicular arteries. The testicular artery branched from the cranial renal artery which, in turn, originated from the cranial (thoracoabdominal) segment of the descending aorta (aorta descendens). This portion of the aorta ran mid-ventral to the spinal column and between the lungs, and terminated beneath the third lumbar vertebra. The left and right cranial renal arteries (arteriae renales craniales) arose from the ventrolateral aspect of the cranial segment of the aorta where it passed between the cranial divisions of the kidney, approximately 3–5-cm caudal to the last vertebral rib. When viewed from the ventral aspect, the cranial renal arteries were concealed by the overlying caudal vena cava.

The first branches (unnamed) of the cranial renal artery emerged approximately 1–2 cm from the origin of the vessel and supplied the cranial division of the kidney (Figs 1 and 2a–d). More distally, a variable number of testicular arteries (between 1 and 3) branched off from the cranial renal artery, running into the testis midway along its dorsomedial border (Figs 1 and 2a–d). Small branches of the testicular arteries were observed to supply the epididymis. This pattern of blood supply to the testes, whereby both the testicular artery and cranial renal artery arose from a common trunk on both sides of the aorta, was present in 54.2% of the specimens and represented the general pattern observed.

The accessory testicular artery (arteria testicularis accessoria)

In some instances one or more additional vessels were observed to arise directly from the aorta unilaterally or bilaterally and to supply the testes (Fig. 2a–d). These accessory testicular arteries were present in 45.8% of the specimens examined and were 0.15–0.4-cm in diameter and up to 6.5-cm in length. They originated approximately 1.1–1.8-cm cranial to the origin of the cranial renal artery, before running ventrolaterally onto the dorsomedial surface of the testis.

Due to variations in the positioning (unilaterally or bilaterally) and the number of the accessory testicular arteries, various architectural types based on the pattern of vascularization of the testes could be identified in the ostrich.

Type A: As for the general pattern (bilateral origin of the testicular and cranial renal arteries from a common branch of the aorta), but with a single accessory testicular artery on either side of the aorta (12.5% of specimens) (Fig. 2a).

Type B: As for the general pattern, but with a single accessory testicular artery on the right side only. No accessory vessels on the left side (25% of specimens) (Fig. 2b).

Type C: As for the general pattern, but with two accessory testicular arteries on the right side only. No accessory vessels on the left side (4.1% of specimens) (Fig. 2c).

Type D: As for the general pattern, but with a single accessory testicular artery on the right side from which branched the right cranial ureterodeferential branch (4.1% of specimens) (Fig. 2d).

The deferent duct (*Ductus deferens*)

Along its length, the ductus deferens was supplied by cranial, middle and caudal ureterodeferential branches emanating from various sub-divisions of the aorta (Fig. 1).

The cranial ureterodeferential branch (Ramus ureterodeferentialis cranialis)

The cranial ureterodeferential branch originated from the caudal aspect of the cranial renal artery where it crossed the ventral surface of the epididymis. This branch ran caudomedially and supplied the cranial part of the ductus deferens and adjacent ureter by means of smaller branches. It continued caudally on the ventromedial surface of the ipsilateral kidney for a distance of 11–12.8 cm, running parallel to the aorta and ductus deferens to which it was related medially, before joining the middle renal artery (Fig. 1). This bilateral anastomosis between the cranial ureterodeferential branch and the middle renal artery effectively created a collateral arterial circulation to the ductus deferens and was observed in all the specimens (Fig. 1). However, in one bird (4.1% of the specimens), the right cranial ureterodeferential branch was seen to originate from the right accessory testicular artery (Fig. 2d).

The middle ureterodeferential branch (Ramus ureterodeferentialis media)

One or two middle ureterodeferential branches were observed to originate from the middle renal artery (arteria renalis media). These vessels ran ventrolaterally to supply the adjacent deferent duct and ureter (Figs 1 and 3–7).

In 70.8% of the specimens, the middle renal artery, together with the caudal renal artery (arteria renalis caudalis), arose from a common trunk, the common renal artery (arteria renalis communis) situated at the base of the sciatic artery (arteria ischiadica) (Fig. 1). The sciatic artery emerged bilaterally from the middle (sacrolumbar) segment of the aorta (Figs 1 and 3–7) in the vicinity of, or just caudal to, the acetabulum and approximately at the caudal poles of the middle divisions of the kidneys. The middle segment of the aorta ran ventral to the caudal lumbar vertebra, medially between the caudal divisions of the kidneys and into the sacral region where it continued caudally to form the caudal segment of the aorta.

A number of variations in this general pattern were, however, observed. In one specimen both the left and right common renal arteries arose from a single common trunk (truncus renalis communis) emanating from the ventral surface of the aorta close to the origin of the sciatic arteries (Fig. 3). In 25.1% of the specimens, the middle and caudal renal arteries on either side arose independently from the base of the sciatic artery (Fig. 4).

In some instances, the arterial supply of the middle ureterodeferential branch was augmented by additional vessels. In one specimen, the right ductus deferens was additionally supplied by a right ventrolateral arterial branch (accessory ureterodeferential branch), originating directly from the aorta just caudal to the origin of the sciatic arteries (Fig. 5). In another specimen, both the left and right ductus deferentes received accessory ureterodeferential branches which arose from a common accessory ureterodeferential trunk, originating from the same region of the aorta as the single accessory vessel described above (Fig. 6).

The caudal ureterodeferential branches (Rami ureterodeferentiales caudales)

Two to three caudal ureterodeferential branches were observed to split from the pudendal artery (arteria pudenda – previously named the internal pudendal artery by Nishida, 1964 and Pintea et al., 1967) and to supply the ductus deferens and ureter in the pelvic region via a variable number of thinner vessels (Fig. 1). The pudendal artery, as well as the lateral caudal artery (arteria lateralis caudae – previously named the external pudendal artery by Nishida, 1964 and Pintea et al., 1967) originated from the internal iliac artery which branched from the caudal segment of the aorta (Fig. 1). The lateral caudal artery supplied the lateral wall of the pelvic region.

In a single specimen the right ductus deferens received a short branch from the right internal iliac artery. This branch originated approximately 2-cm proximal to the division of the internal iliac artery into the lateral caudal and pudendal arteries (Fig. 7).

Phallus (*Phallus*)

Between one to three relatively thin branches of the pudendal artery were observed to run caudoventrally towards the cloaca which they vascularized. Other branches continued towards the root of the phallus where they formed an arterial plexus or network (Fig. 1).

Discussion

Very few studies have provided information on the blood supply to the male reproductive organs in birds. The most comprehensive report is that of Nishida (1964) in the domestic fowl (*Gallus domesticus*) and, to a lesser extent, the study of Bhaduri et al. (1957) in the pigeon (*Columbia livia*). This information has been supplemented by miscellaneous data, mainly on the domestic fowl (Lake, 1971; Kurihara and Yasuda, 1975). The present study provides the first detailed description of the arterial supply to the male reproductive tract of the ostrich and adds to the limited comparative data available on birds in general.

The origin of the testicular artery from the cranial renal artery in the ostrich is similar to that reported in the domestic fowl (Nishida, 1964; Kurihara and Yasuda, 1975) and pigeon (Bhaduri et al., 1957). This was considered to be the general pattern of arterial supply to the testes in the ostrich and occurred in 54.2% of the specimens examined (see Fig. 1). The incidence of this particular pattern in the fowl is reported to be 54.5% (18 out of 33 specimens examined, Kurihara and Yasuda, 1975) and represents the type IV variation described by both Nishida (1964) and Kurihara and Yasuda (1975). The remarkable similarity in the incidence of this pattern in both the fowl and ostrich would seem to lend support to the suggestion that this is the general pattern observed in birds. Similarly, the presence of accessory testicular arteries and their variations in the ostrich are comparable to most of those described for the domestic fowl (Nishida, 1964; Kurihara and Yasuda, 1975). The type A variation described for the ostrich (single, bilateral accessory testicular arteries) is similar to the type I variation reported in the fowl (Nishida, 1964; Kurihara and Yasuda, 1975) and occurs, respectively, in 9% (Kurihara and Yasuda, 1975) and 12.5% of fowls (Nishida, 1964) and ostriches (this study) examined. Likewise, the type B variation in the ostrich (single accessory testicular artery on the right side only) is similar to the type III variation reported in the fowl (Nishida, 1964; Kurihara and Yasuda, 1975), although the reported incidence is higher in the ostrich (25%) than in the fowl (9%–Kurihara and Yasuda, 1975). The type C and D variations reported in this study appear to be unique to the ostrich, since they have not been reported previously in birds. However, the study of more specimens from a wider range of avian species would probably reveal a common range of variations in respect of the accessory testicular arteries. It is also not known why the accessory testicular artery described in the ostrich is more commonly present on the right side than on the left side. The origin of a cranial ureterodeferential branch from the cranial renal artery (which supplies the cranial aspect of the ductus deferens) is also similar in both the domestic fowl (Nishida, 1964) and the ostrich. However, the anastomosis observed between the caudal continuation of the cranial ureterodeferential branch and the middle renal artery in the ostrich has not been reported in other birds and may be a distinctive feature of this species.

In the ostrich, the middle segment of the deferent duct is supplied by the middle ureterodeferential branch/branches that originate from the middle renal artery. In 70.8% of the specimens examined, this vessel, together with the caudal renal artery, arises from a common trunk emanating from the base of the sciatic artery. In this study, the common trunk is named the common renal artery (arteria renalis communis). A similar situation is apparent in the domestic fowl, although the common trunk referred to above is not named in any of the studies describing or illustrating this vessel (Nishida, 1964; Siller and Hindle, 1969; Kurihara and Yasuda, 1975). Two variations in this pattern are evident in the ostrich. In one specimen both the left and right common renal arteries arose directly from the aorta via a common trunk. In 25.1% of the specimens, the middle and caudal renal arteries originated independently from the sciatic artery. This variation is reported to be the standard pattern in the pigeon (Bhaduri et al., 1957). The existence of occasional accessory vessels augmenting the supply of the middle ureterodeferential branch to the ureter and deferent duct in the ostrich has also been reported in the domestic fowl (Nishida, 1964). However, the presence, albeit in one specimen, of a common accessory ureterodeferential trunk from the aorta that supplies both the left and right ductus deferens, has not been reported in other birds.

The caudal segment of the ductus deferens and ureter in the ostrich is vascularized by a number of caudal ureterodeferential branches emanating from the pudendal artery, which

in turn arises from one of the terminal branches of the aorta, the internal iliac artery. The pattern of branching of the internal iliac artery in the male ostrich is basically similar to that reported in the domestic fowl and pigeon (Bhaduri et al., 1957; Nishida, 1964; Pintea et al., 1967), although the nomenclature used is inconsistent. In one ostrich specimen the caudal region of the right ductus deferens/ureter was additionally supplied by an arterial branch arising proximally from the right internal iliac artery. This variation has also been reported or illustrated in the domestic fowl by Nishida (1964) and in the pigeon by Bhaduri et al. (1957), although the terminology used in the latter description is confusing.
In the male ostrich the cloaca and phallus are supplied by branches of the pudendal artery as previously reported for the domestic fowl (Nishida, 1964; Lake, 1971). The report that the cloaca is also supplied by branches of the external pudendal artery (lateral caudal artery) (Nishida, 1964) could not be confirmed in the present study. The network of arterial vessels located at the base of the phallus appears to be peculiar to the ostrich.
In conclusion, the pattern of the blood supply to the reproductive organs of the male ostrich is generally similar to that of the domestic fowl and pigeon. A few noteworthy differences include:

- The origin of the right cranial ureterodeferential branch from the right accessory testicular artery in one specimen.
- The anastomosis observed between the caudal continuation of the cranial ureterodeferential branch and the middle renal artery.
- The presence, in one specimen, of accessory ureterodeferential branches from the aorta that supply both the left and right deferent ducts in the sacral region.
- The existence of an arterial plexus or network surrounding the root of the phallus.

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Figures

Fig. 1. Diagrammatic representation of the arterial supply to the reproductive organs of the male ostrich. Ventral view.

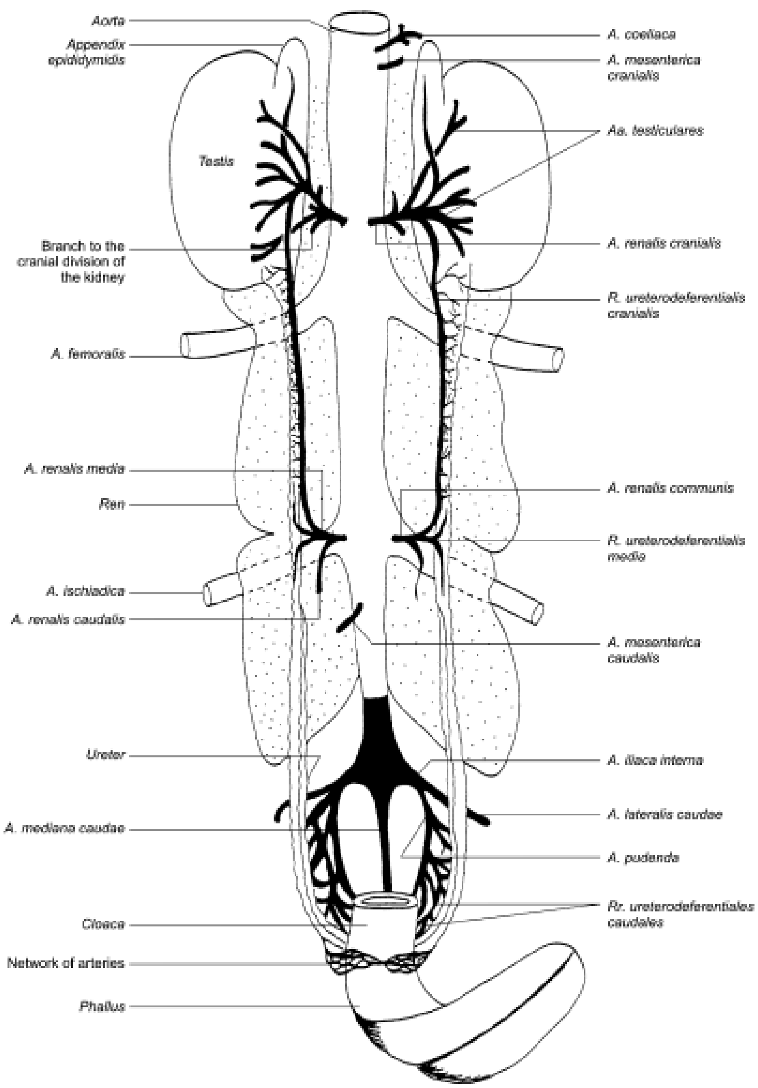

Fig. 2. Diagrammatic representation of the variations in the pattern and origin of the accessory testicular arteries. Ventral view.

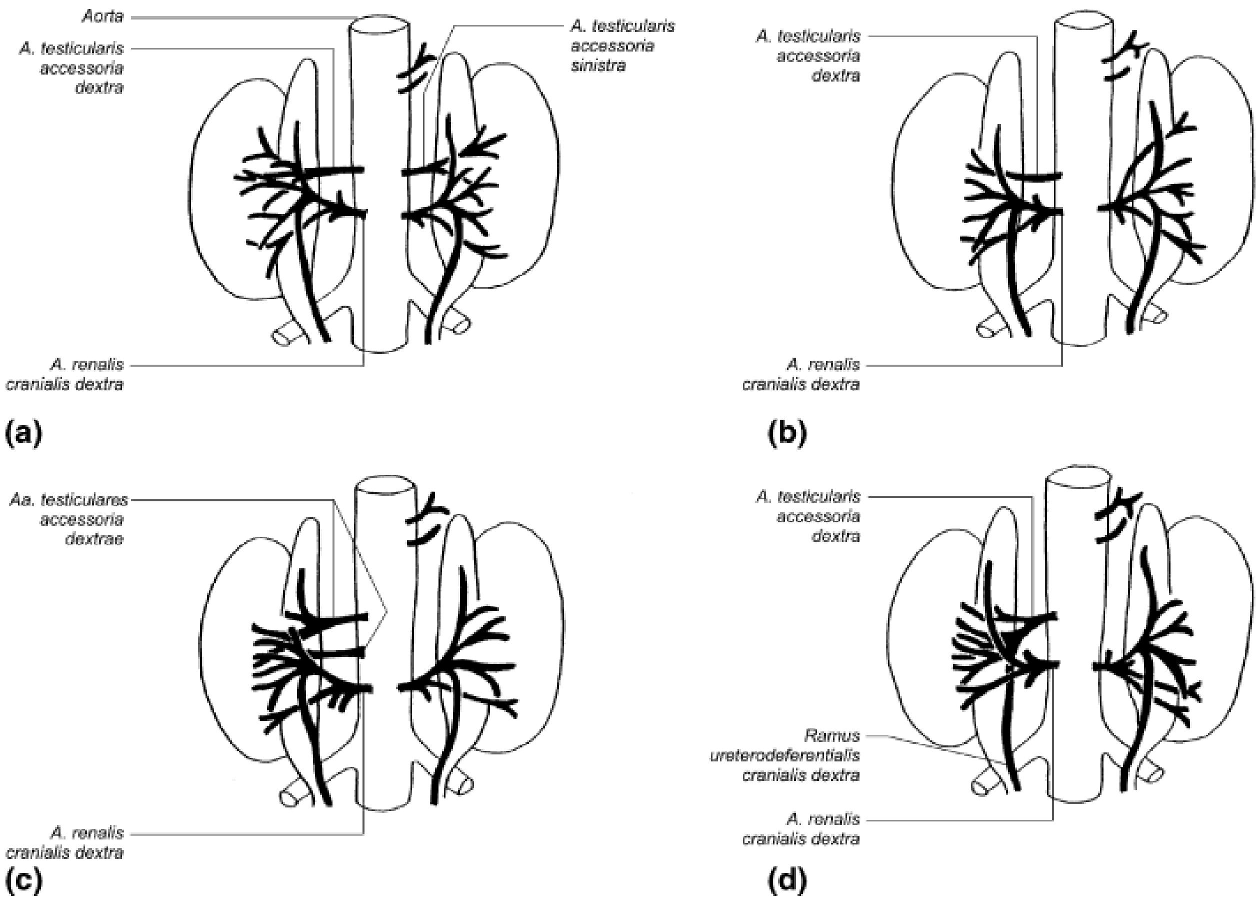

Fig. 3. Ventral view of the sacrolumbar segment of the aorta showing the origin of the common renal arteries from a common renal trunk.

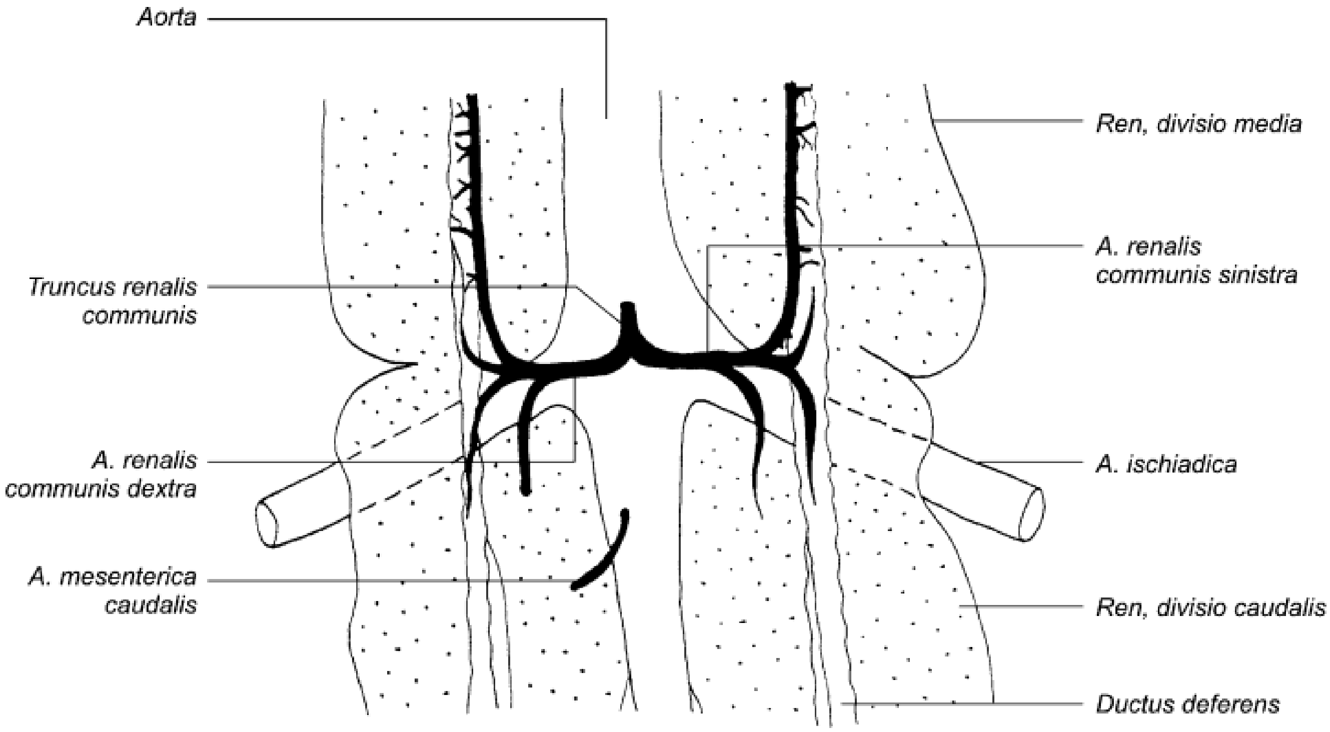

Fig. 4. Ventral view of the sacrolumbar segment of the aorta showing the separate origin of the middle and caudal renal arteries from the sciatic artery.

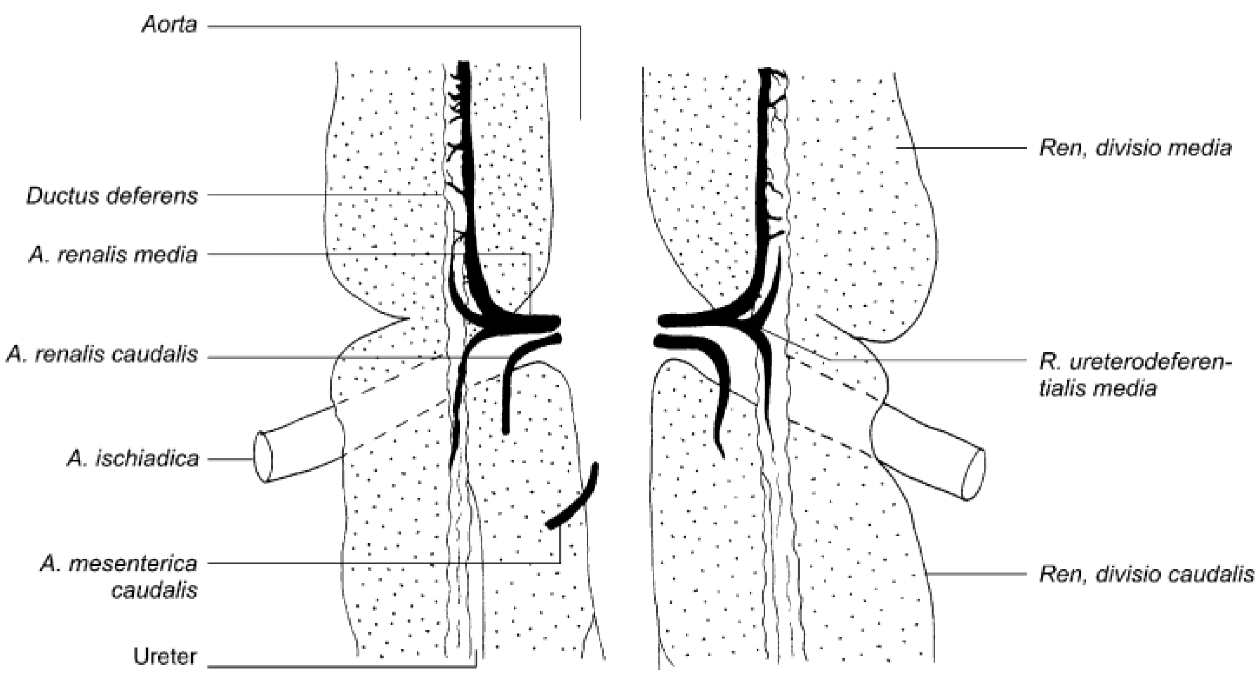

Fig. 5. Ventral view of the sacrolumbar segment of the aorta showing the presence of a right accessory ureterodeferential branch from the aorta.

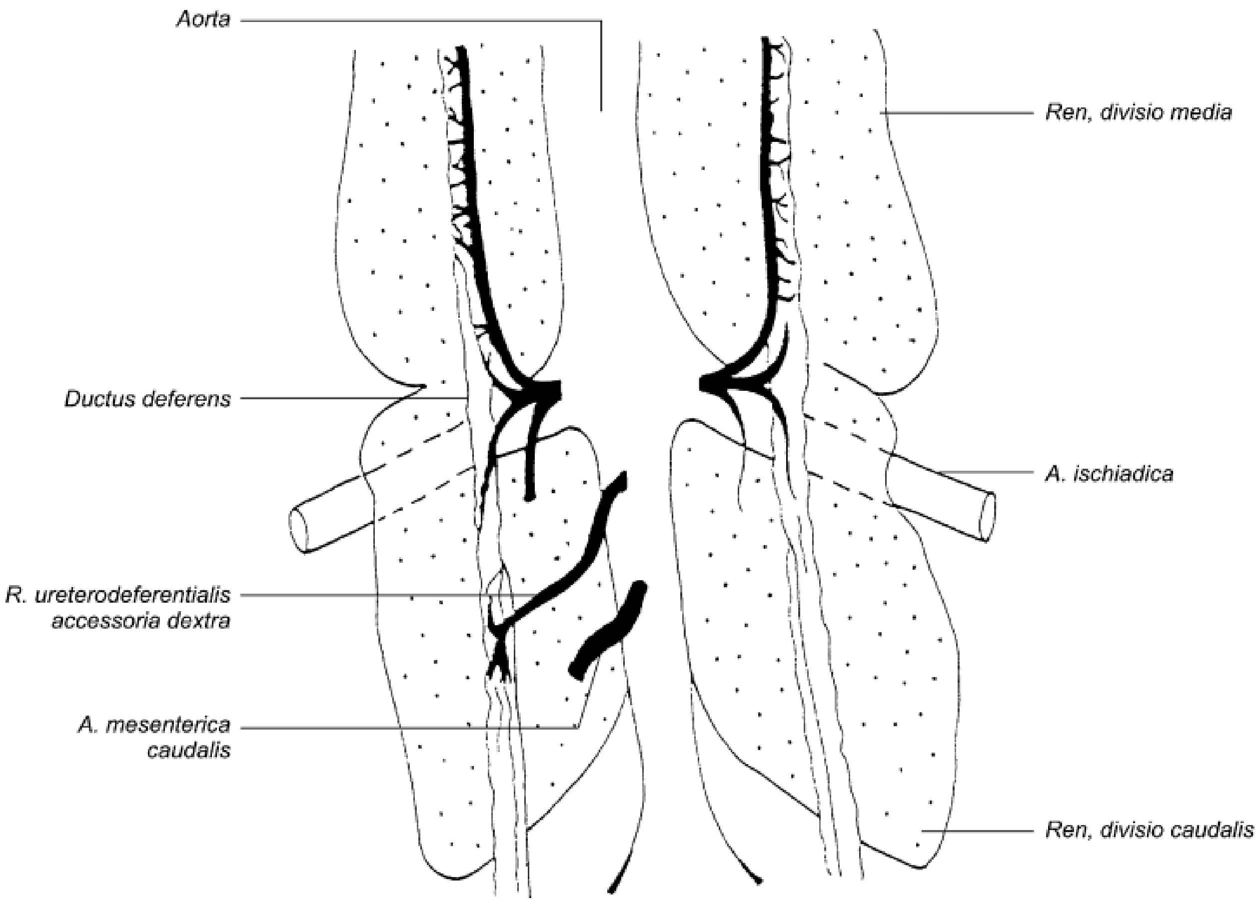

Fig. 6. Ventral view of the sacrolumbar segment of the aorta showing the presence of a common accessory ureterodeferential trunk bifurcating into left and right accessory ureterodeferential branches.

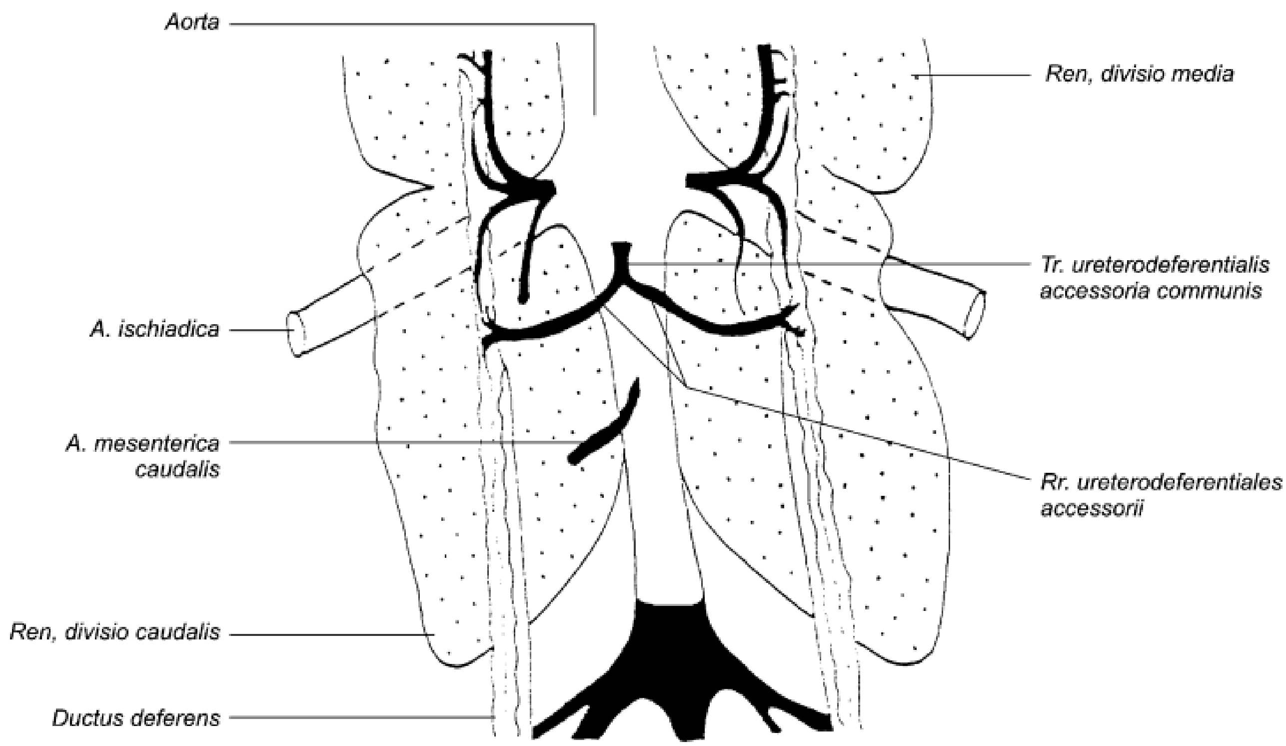

Fig. 7. Ventral view of the sacrolumbar segment of the aorta showing the presence of an occasional ureterodeferential branch from the right common iliac artery to the right ductus deferens and ureter.