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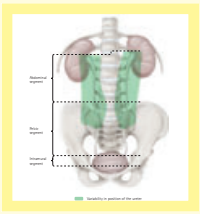

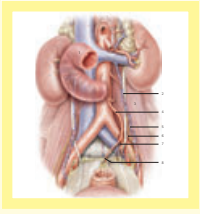

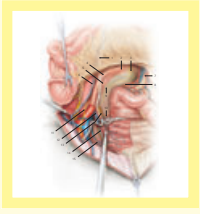

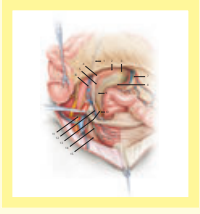

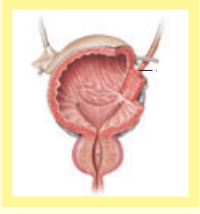

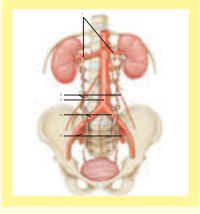

Surgical Atlas

Surgical anatomy of the ureter

Rosemarie Fröber

Department of Anatomy, Friedrich Schiller University, Jena, Germany

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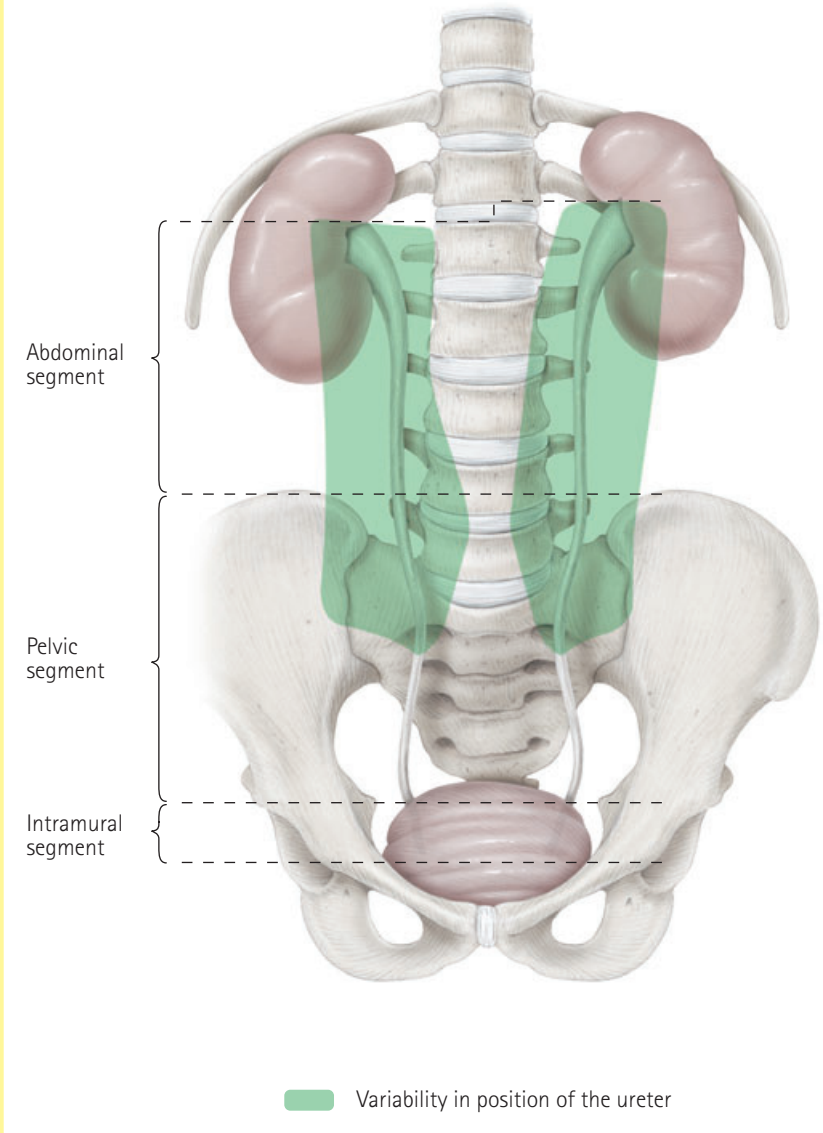
INTRODUCTION

Iatrogenic injury to the urinary tract can be caused by any surgeon operating in or around the pelvis and the retroperitoneal abdominal space, with a general incidence of 0.3–1.5%. This includes gynaecologists, general surgeons, urologists, vascular surgeons, neurosurgeons and orthopaedic surgeons. In addition, the impact of technological advances within the surgical field, such as the use of laparoscopy for general surgical and gynaecological procedures, and the application of endoscopic approaches to urological disease, is elucidated here [1].

The urinary tract is extremely vulnerable to intraoperative injury for a variety of reasons. Operating in a hostile environment, such as that encountered with repeat surgery, significant inflammation and a large neoplasm, puts the urinary tract at even greater risk. Injuries to the ureter are the most common, because the ureter is similar in appearance to vascular structures, is difficult to identify as a result of its close adherence to the posterior peritoneum, and can be encountered at virtually any level in the retroperitoneum and upper pelvis. When these points are considered along with the inherent difficulties with the occasional unexpected congenital anomaly, such as ureteric duplication or retrocaval ureter, it is easy to understand how vulnerable to injury the ureter can be. Thus it is essential that every surgeon operating in this area must be familiar with the special anatomy of the ureter.



STRUCTURING AND TOPOGRAPHIC RELATIONS OF THE URETER

Figure 1

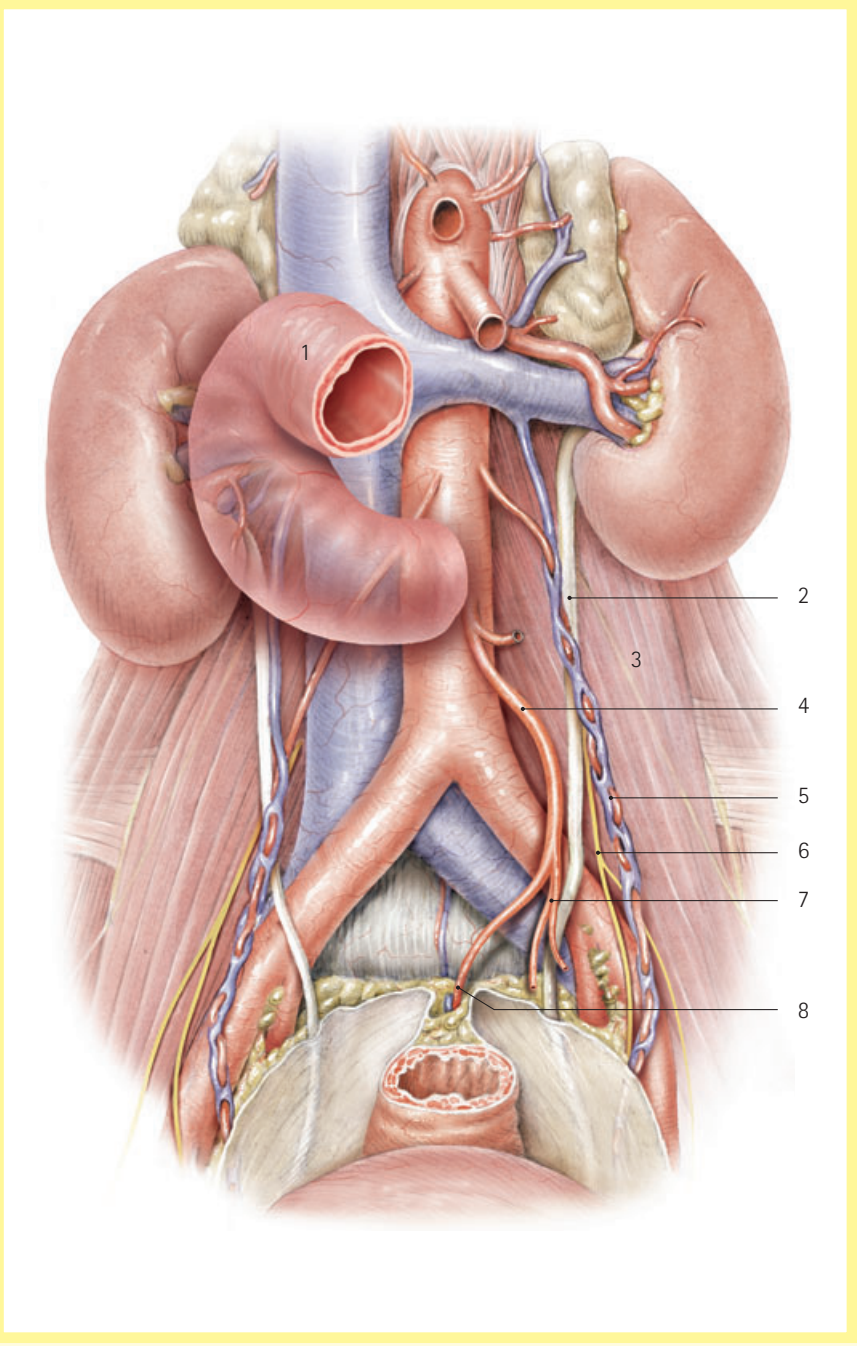
The variability in the position of the ureter to the adult skeleton.

In adults the ureter is 25–30 cm (in neonates 6.5–7.0 cm) long, with a diameter of 1.5–6 mm. In the retroperitoneum, the ureter is situated just lateral to the tips of the transverse processes of the lumbar vertebrae. Urologists divide the ureter beyond the ureteropelvic junction (PUJ) arbitrarily into the proximal, middle and distal part. According to the international anatomical terminology the ureter consists of the abdominal, the pelvic and the intramural segment.

Figure 2

The retroperitoneal space with the anatomical structures surrounding the left and the right ureter.

1 Duodenum
2 Ureter
3 Psoas
4 Inferior mesenteric artery
5 Testicular/ovarian artery and vein
6 Genitofemoral nerve; femoral and genital branches
7 Sigmoid arteries
8 Superior rectal artery



The abdominal segment of the ureter extends from the renal pelvis to the pelvic brim. The right ureter begins behind the descending part of the duodenum. Just below their origin the ureters are crossed by gonadal (testicular or ovarian) vessels (the so-called 'bridge over water'). Behind the ureter the genitofemoral nerve (or its genital and femoral branches) runs on top of the psoas. On the left side, the sigmoid arteries and veins embedded in the sigmoid mesocolon run in front of the ureter towards the sigmoid colon. The inferior mesenteric artery and its terminal branch, the superior rectal artery, follow a curved course close to the left ureter. Proceeding from medial to lateral, the following sequence of structures is found: superior rectal vessels; left ureter; left testicular or ovarian vessels. Just above the entry to the pelvis, the ureter is still covered by peritoneum by virtue of the ureteric fold. Next to the ureteric fold, the gonadal vessels form an adjacent fold (in female, infundibulopelvic or suspensory ligament of ovary).

Note: One of the most common areas of ureteric injury is near the pelvic brim in close relation to the peritoneal fold of the gonadal vessels (for instance the ovarian vessels in the infundibulopelvic ligament of ovary).

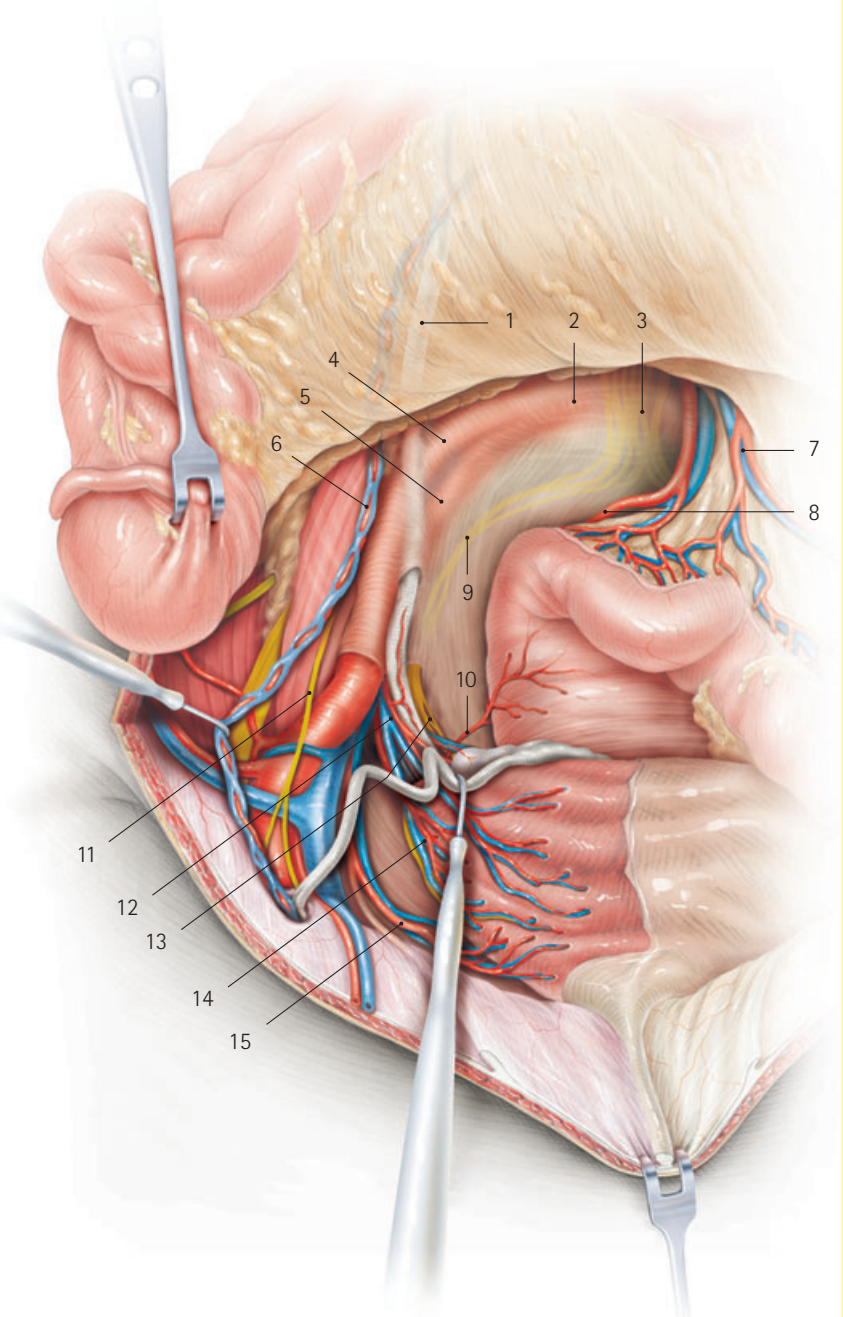


Figure 3

The pelvic space in the male, with neurovascular structures surrounding the pelvic segment of the right ureter (cranial view) (modified from Spitzer in [2], Fig. 223).

1 Ureter
2 Common iliac artery
3 Superior hypogastric plexus
4 External iliac artery
5 Internal iliac artery
6 Testicular artery and vein
7 Sigmoid arteries and veins
8 Superior rectal artery and vein
9 Hypogastric nerve
10 Middle rectal artery
11 Genitofemoral nerve
12 Artery to vas deferens
13 Inferior hypogastric (pelvic) plexus
14 Inferior vesical artery, vein and vesical plexus
15 Superior vesical artery and vein

The pelvic segment of the ureter is ≈15 cm long and accounts for roughly half of its total length. At the level of its beginning at the pelvic inlet, it crosses the common iliac vessels near their bifurcation (on the left side commonly anterior to the common iliac artery and on the right side commonly anterior to the external iliac artery). Within the pelvis the ureter can be divided into two portions. The descending part runs caudally still covered by peritoneum. It is dorsally accompanied by the internal iliac artery and its visceral branches as well as marked venous plexuses. Projected on to the lateral wall of the pelvis, the descending part of the ureter crosses the obturator artery, vein and nerve.

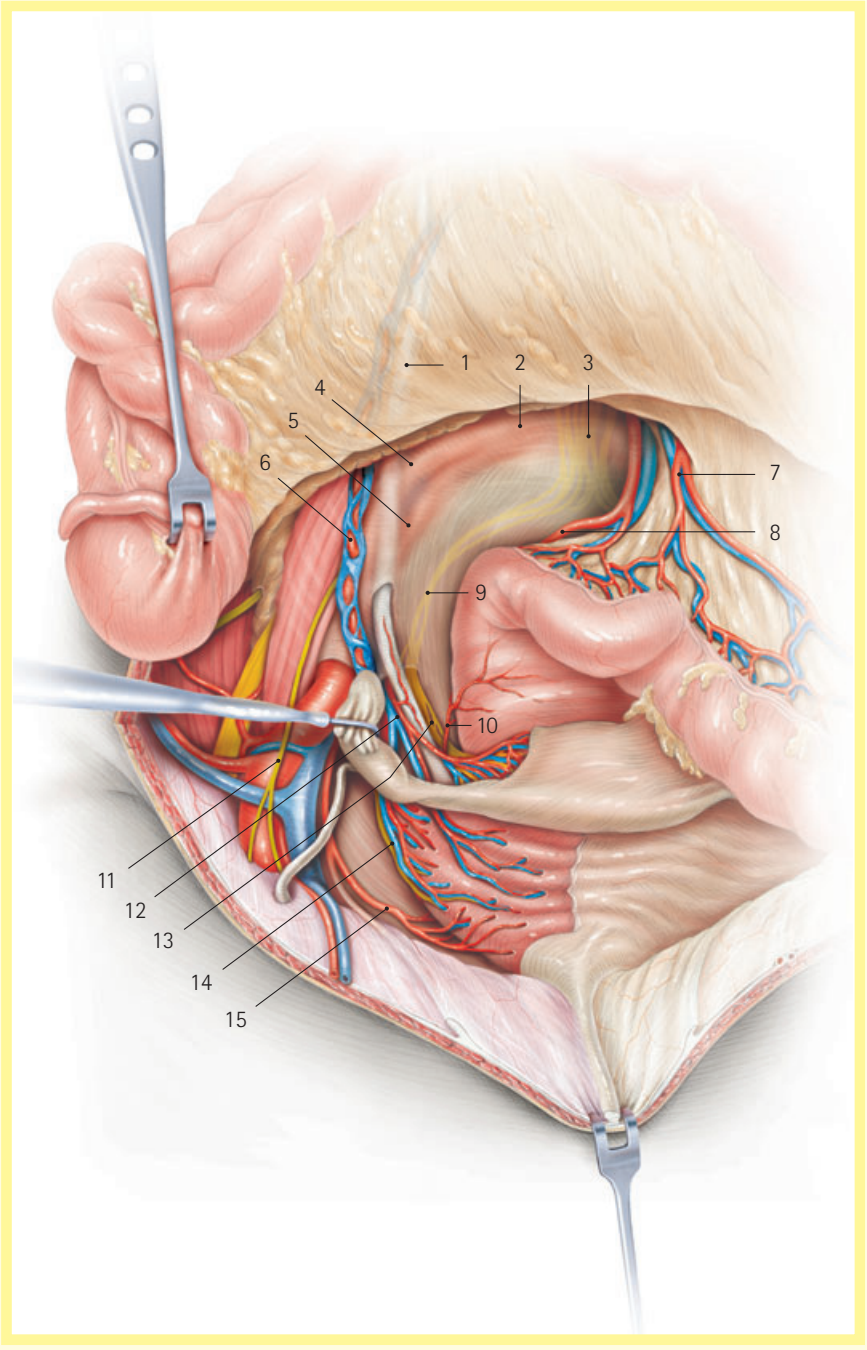
In the male, the following bent part of the pelvic segment of the ureter swings caudally in a convex curve and runs ventrally; the vas deferens loops over this part. Just before it enters the bladder, the ureter passes the ampulla of the vas deferens and the seminal vesicles. Depending on its size, the seminal vesicles or the ampulla of the vas deferens might overlap the ureter. At this level, the ureter runs to the bladder accompanied by inferior vesical vessels and the inferior hypogastric (pelvic) plexus.

Figure 4

The pelvic space in the female with neurovascular structures surrounding the pelvic segment of the right ureter (cranial view) (modified from Spitzer in [2], Fig. 223). Key as in Fig. 3, except 6, Ovarian artery and vein; 12 Uterine artery and veins.

In the female, the descending part of the pelvic segment of the ureter courses posterior to the ovary. Following that, the bent part passes the middle rectal artery in the lateral ligament of the rectum (paraproctium), swings in a convex curve and crosses the uterine vessels in a sagittal direction near, i.e. 1.5–2 cm (occasionally even 1–4 cm) away from the margin of the cervix of uterus. At this level, the ureter reaches the base of broad ligament of uterus (paracolpium) described by Kocks as the cardinal ligament and by Mackenrodt as the ligamentum transversale colli [3]. The inferior hypogastric (pelvic) nerve plexus is positioned a little lower than the ureter, with the middle rectal vessels piercing almost at its centre. Finally, the terminal ureter runs forward, accompanied by the neurovascular bundle of the bladder. Just before entering the bladder, it passes the anterior vaginal fornix. As a rule, the left ureter has a more close relation to the anterior wall of the vagina than the right [4].

Note the close proximity of the ureter to the uterine vessels. This is the site where ureteral injuries most commonly occur during gynaecological procedures. In case of vaginal surgery, there is a high risk of injury especially for the left ureter.



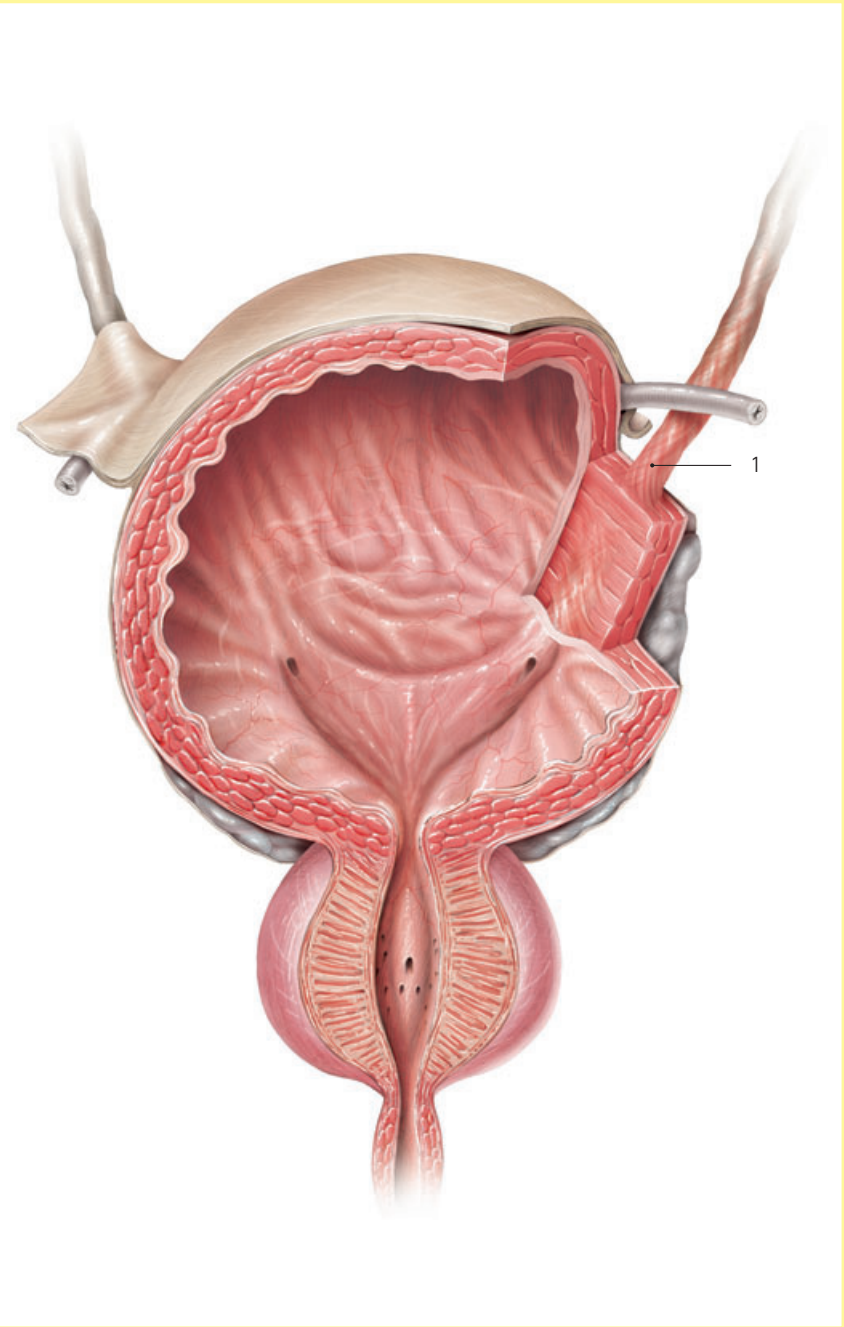


Figure 5

The intramural segment of the ureter with the bladder wall and the muscular layer of Waldeyer in the male.

1 Muscular layer of Waldeyer

The intramural segment of the ureter runs obliquely through the bladder wall. Near the bladder the terminal ureter is enveloped by the muscular layer of Waldeyer [5]. It coalesces with bundles of the detrusor muscle in the bladder wall and consists of coarser longitudinally arranged muscle bundles.

Reflux of urine is prevented because the ureter passes diagonally through the bladder wall musculature for a short distance before entering the bladder lumen. The length of this intramural part of the ureter in adults is 1.2–2.5 cm (in neonates 0.5–0.8 cm).

SUPPLYING ARTERIES

Figure 6

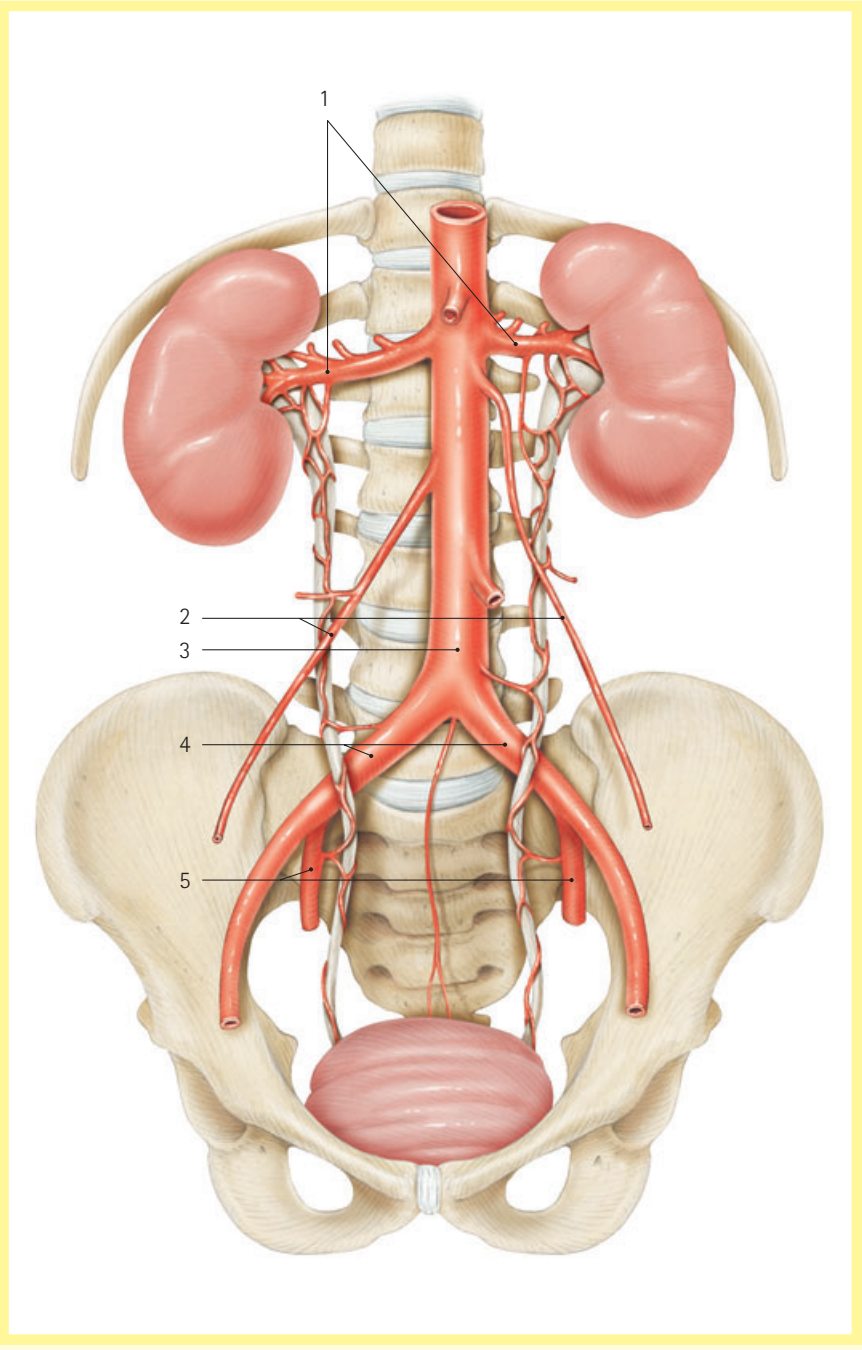
The arterial supply to the abdominal segment and the descending portion of the pelvic segment of the ureter.

1 Renal arteries
2 Ovarian/testicular arteries
3 Aorta
4 Common iliac arteries
5 Internal iliac arteries

At the level of the PUJ, branches of the renal artery supplying the renal pelvis communicate with the adventitial vascular plexus of the adjacent part of the ureter. Moreover, the renal artery participates in supplying the adjacent portion of the ureter by major descending branches (30.7% according [6]).

The following abdominal segment of the ureter is supplied by branches of the testicular or ovarian artery (7.7% according [6]). In addition, there are also branches coming from the aorta and the common iliac arteries (15.4% according [6]) which supply the adventitial vascular plexus. On the whole, the nutrient branches for the abdominal segment of the ureter generally move up from the medial. By contrast, the descending portion of the pelvic segment of the ureter is supplied from branches of the internal iliac artery (8.5% according [6]). These nutrient branches generally move up to the ureter from the lateral.

Note: The nutrient arteries generally approach the ureteric wall from one direction. Above the pelvic brim, the surgeon must be aware on the medial side, and below the pelvic brim on the lateral side of the ureter. Ligation of the renal artery does not cause necrosis of the ureter or the renal pelvis because of the multiple nutrient branches at the level of the PUJ.



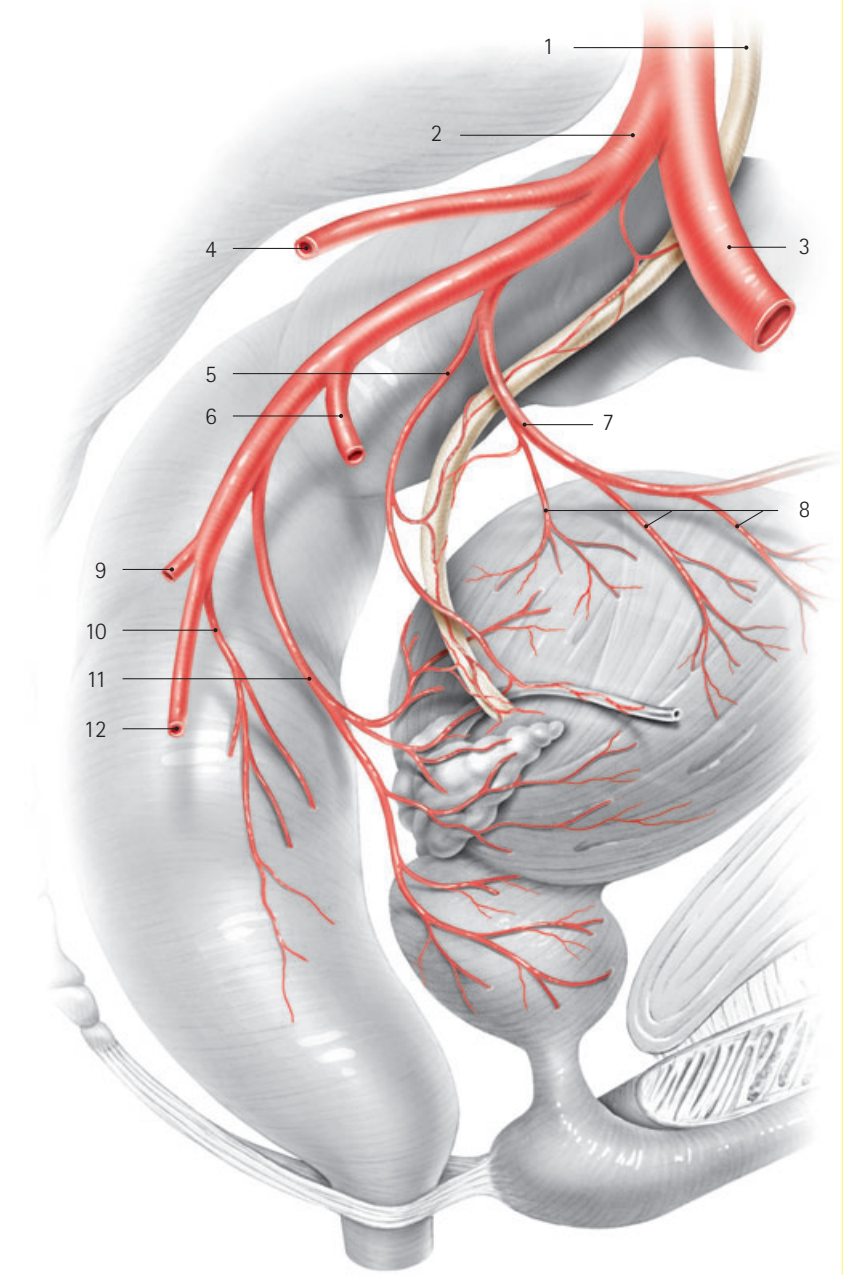


Figure 7

Arterial supply of the bent portion of the pelvic segment of the ureter in the male (lateral view).

1 Ureter
2 Internal iliac artery
3 External iliac artery
4 Superior gluteal artery
5 Artery to vas deferens
6 Obturator artery
7 Umbilical artery
8 Superior vesical arteries
9 Inferior gluteal artery
10 Middle rectal artery
11 Inferior vesical artery
12 Pudendal artery

The bent portion of the pelvic segment of the ureter is supplied from branches of the internal iliac artery. Belonging to it are the superior vesical arteries (1–4) arising from the umbilical artery (12.8% according [6]). The terminal part of the umbilical artery is obliterated to form the median umbilical ligament. Moreover, the inferior vesical artery, arising from the internal pudendal artery or from the inferior gluteal artery (sometimes directly from the internal iliac artery), is chiefly engaged in supplying the lower wall of the retrovesical ureter (12.9% according [6]). Occasionally, the terminal segment of the ureter is also supplied via the middle rectal artery.

In the male, another nutritive branch is the artery to vas deferens, which can arise directly from the internal iliac artery or from the umbilical artery. When running together with the vas deferens to the seminal vesicles, it extends branches to the wall of the bent part of the ureter.

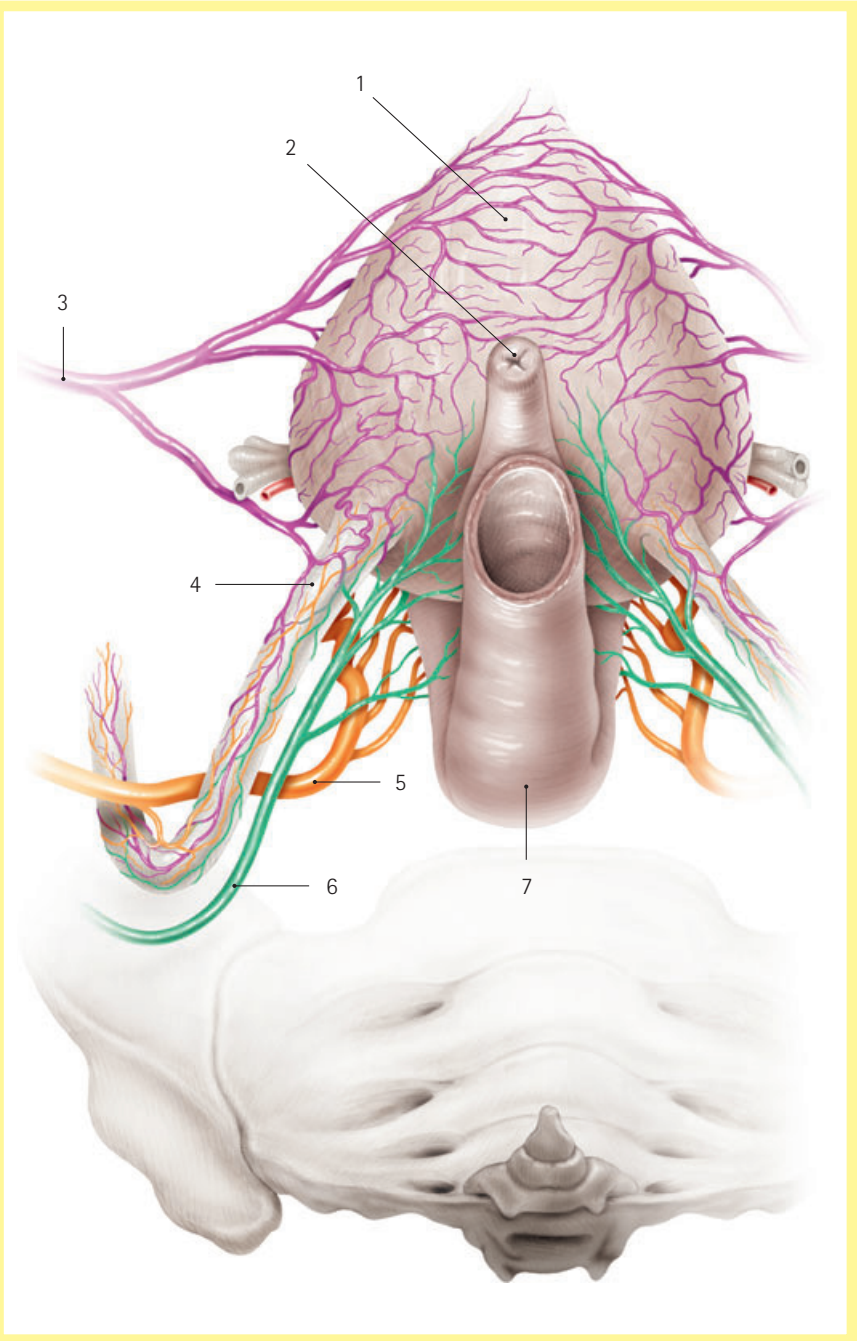
Figure 8

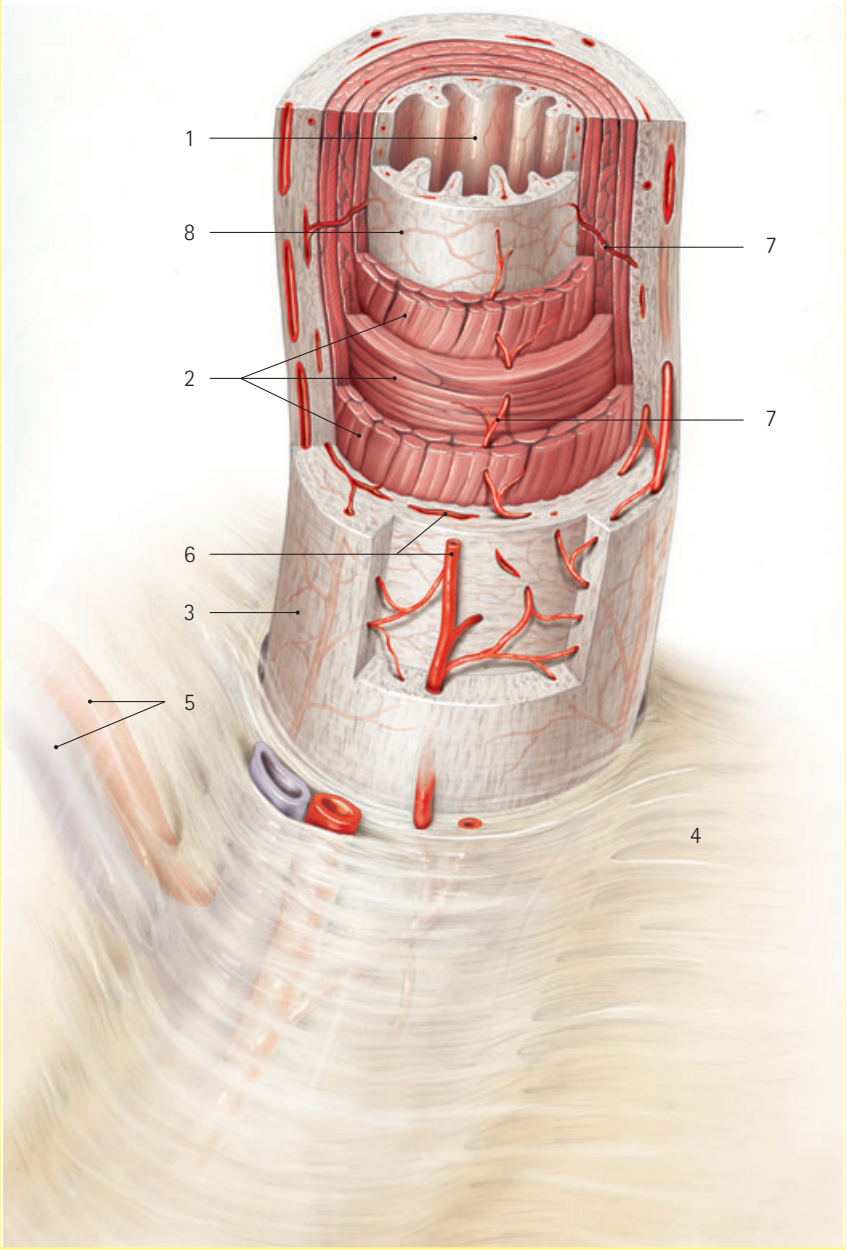
Arterial supply of the terminal ureter in the female (inferior anterior view) (modified from Batke in [7], Fig. 292).

1 Bladder
2 External ostium of the female urethra
3 Superior vesical artery
4 Ureter
5 Uterine artery
6 Inferior vesical artery
7 Vagina

In the female, apart from the superior and the inferior vesical arteries, the uterine artery, as it crosses the ureter, is engaged in supplying the bent portion of the pelvic segment of the ureter. As the crossing is oblique, the ureter is contiguous to the uterine artery for 1–2.5 cm.

Note: The arterial blood supply of the bent portion of the pelvic ureter requires special attention. When operating, the surgeon must watch for the multitude of nutritive branches running its course from neighbouring arteries to the ureter.





URETERIC WALL

Figure 9

Nutrient vascular structures and ureteric wall layers near the bladder.

1 Mucosa
2 Muscle coat
3 Adventitia
4 Mesoureter
5 Supplying artery and vein
6 Adventitial vascular plexus
7 Perforating arteries
8 Mucosal vascular plexus

The lumen of the ureter is coated with urothelium, an epithelium underlying the lamina propria. This mucous membrane contains the finely woven mucosal vascular plexus. The muscle coat, responsible for the bilateral alternating peristaltic movements of the ureter (2–3 cm/s), consists primarily of spirally arranged smooth muscle bundles. In cross section, the bundles form two muscle layers fused by connective tissue. The inner layer is mainly longitudinal in arrangement, and in the outer layer the muscle bundles are arranged circularly. Near the bladder the intrinsic musculature is separated from a third layer, the muscular layer of Waldeyer; it consists of coarser longitudinally arranged muscle bundles, which emerge from the bladder wall into the ureter.

The connective tissue of the adventitia, the ureteric sheath (≈ 2.5 mm thick), contains the adventitial vascular plexus responsible for supplying the ureteric wall. It is divided into an outer and an inner vascular network. The inner one is characterized by densely convoluted, partly corkscrew-like arteries with small perforating arteries running radially and obliquely from there upwards and downwards through the intrinsic musculature and continuing to the mucosal vascular plexus. The outer network, which is coarsely reticulated, contains longitudinal vessels constituting manifold anastomoses.

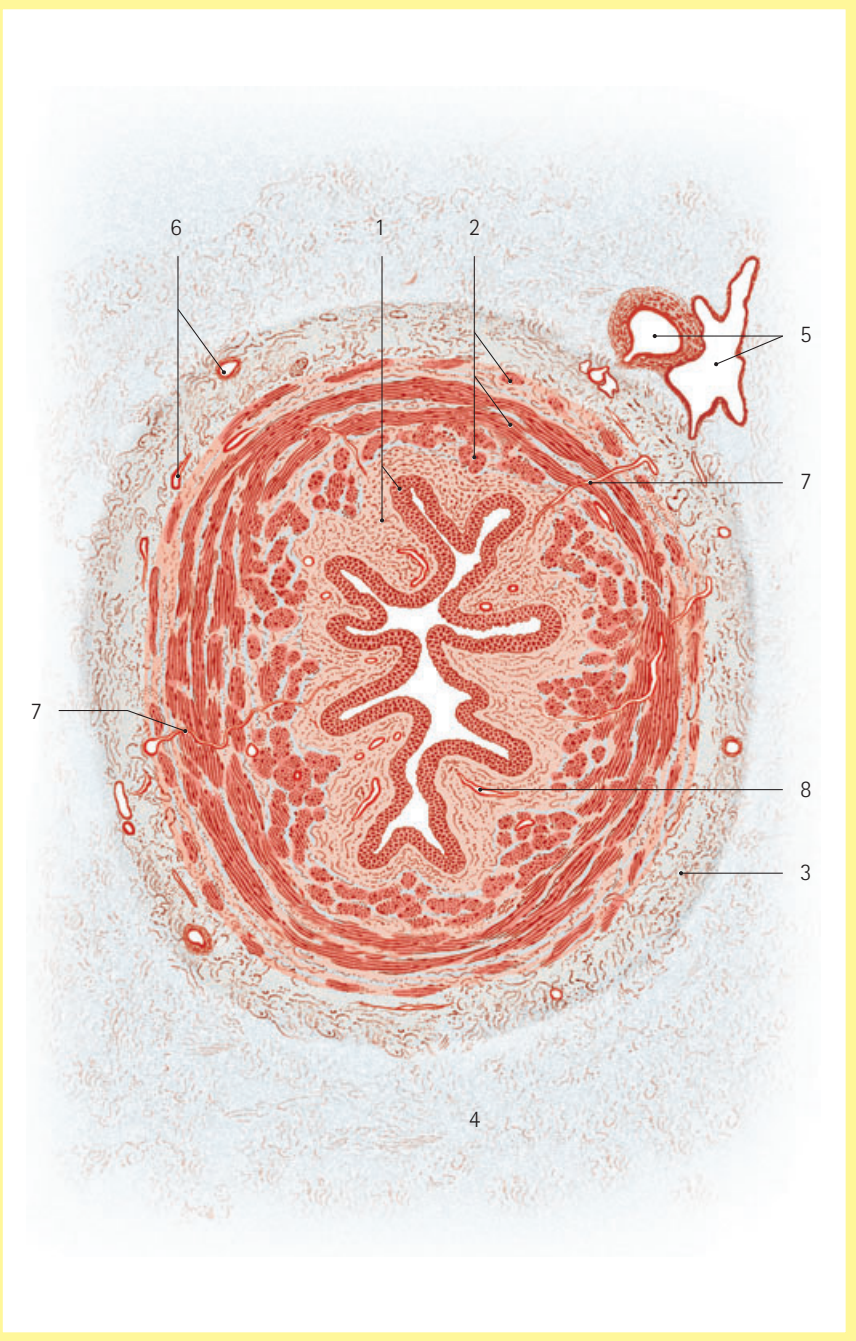
The supplying arteries and veins, generally approaching the ureter from one direction, run through a layer of loose connective tissue to the adventitial vascular plexus. This peri-ureteric connective tissue layer is termed mesoureter. For the surgeon it is feasible to ligate an arterial inflow without necrosis of the ureter, because it is rich in collateral circulation and anastomoses within the adventitial vascular plexus. However, unnecessary and excessive mobilization can devascularize the ureter and increase the risk of postoperative ureteric stricture.

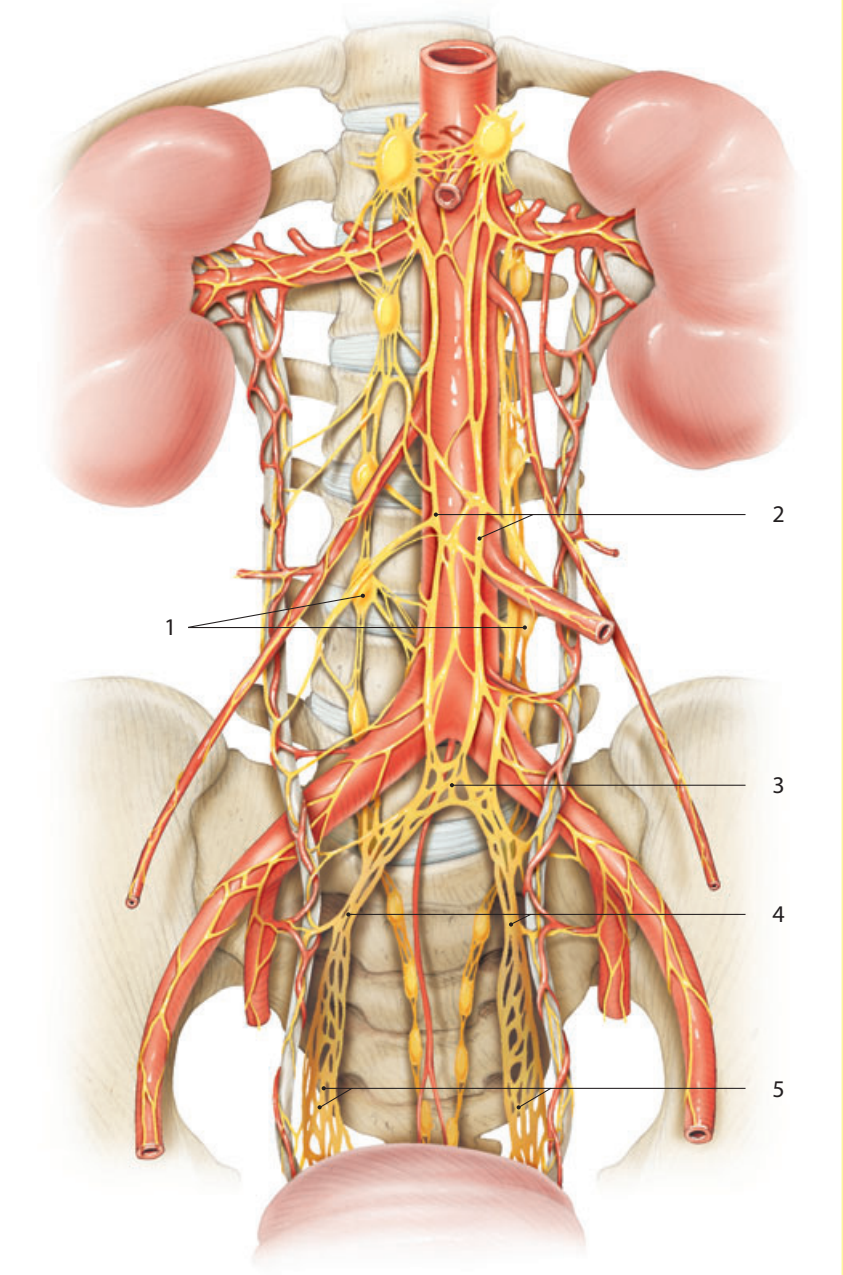
Note: Careful surgical dissection of the ureter within the layer of the mesoureter avoids ischaemia of the ureter.

Figure 10

The nutrient vascular structures in a schematic illustration of a microscopic transverse section of the ureter.

1 Mucosa
2 Muscle coat
3 Adventitia
4 Mesoureter
5 Supplying artery and vein
6 Adventitial vascular plexus
7 Perforating arteries
8 Mucosal vascular plexus





INNERVATION OF THE URETER

Figure 11

Autonomic innervation of the abdominal segment and the descending portion of the pelvic segment of the ureter.

1 Sympathetic trunk
2 Aortic plexus
3 Superior hypogastric plexus
4 Hypogastric nerve
5 Inferior hypogastric (pelvic) plexus

The sympathetic nerves supplying the ureter originate from the aortic plexus and its continuation, the superior hypogastric plexus, the paired hypogastric nerve and the subsequent inferior hypogastric (pelvic) plexus. The nerves accompany the nutrient branches of the neighbouring arteries and form circum-arterial plexuses or run free in the connective tissue. The intramural plexuses consist of unmyelinated visceromotor and viscerosensory fibres. The existence of ganglion cells is disputed. Some authors claim to have detected ganglion cells in the muscle coat of the ureter and the renal pelvis, but others deny the existence of nerve cells in this layer of the ureter.

The superior hypogastric plexus is a fenestrated network of sympathetic pre-ganglionic and visceral afferent fibres, located beneath the level of the peritoneum, just inferior to the bifurcation of the aorta. The hypogastric nerves exit bilaterally at its inferior poles. It can appear as one to three nerve strands, and is found 1–2 cm from the medial aspect of the descending part of the pelvic ureter. It gives an origin to the inferior hypogastric (pelvic) plexus, a complex of interlacing sympathetic and parasympathetic fibres.

Figure 12

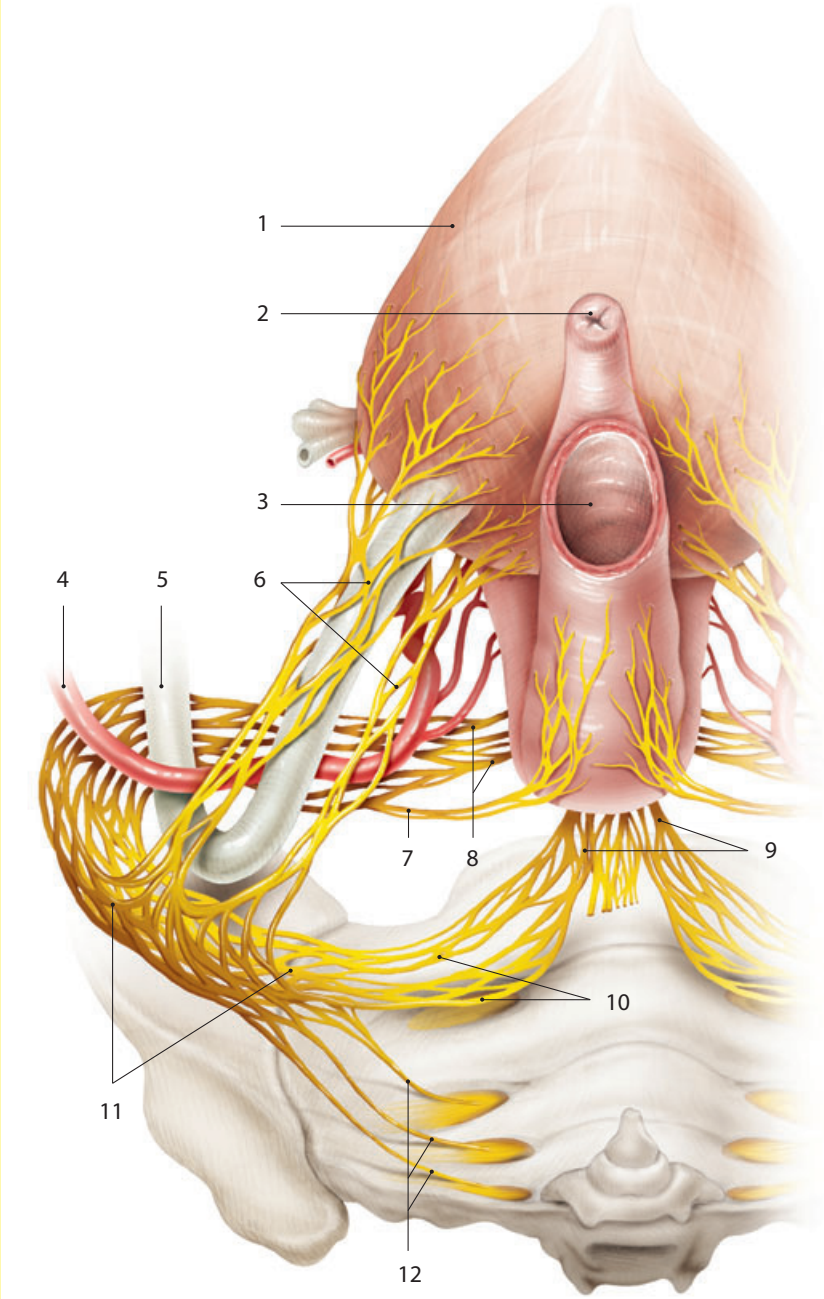
The right-sided pelvic nervous structures in the female (inferior anterior view) (modified from Batke in [7]).

1 Bladder
2 External ostium of the female urethra
3 Vagina
4 Uterine artery
5 Ureter
6 Vesical plexus
7 Vaginal nerve
8 Uterovaginal plexus
9 Superior hypogastric plexus
10 Hypogastric nerve
11 Inferior hypogastric (pelvic) plexus
12 Pelvic splanchnic nerves

The parasympathetic pelvic splanchnic nerves usually arising from the second, third and fourth sacral root traverse the inferior hypogastric plexus before its partition in its specific plexuses for the pelvic viscera.

In the female, the branches of the uterovaginal plexus are themselves positioned a little lower than the uterine artery and the ureter. The branches of the vesical plexus run inferior to the terminal ureter and extend to the trigone of the bladder.

Note: In an antireflux procedure there is a high risk of injury to the nervous structures if dissection is performed dorsally to the trigone and dorsocaudally to the vesico-ureteric junction. Careful dissection close to the terminal ureter (within the layer of mesoureter) avoids intraoperative injury to the pelvic autonomic nerves.



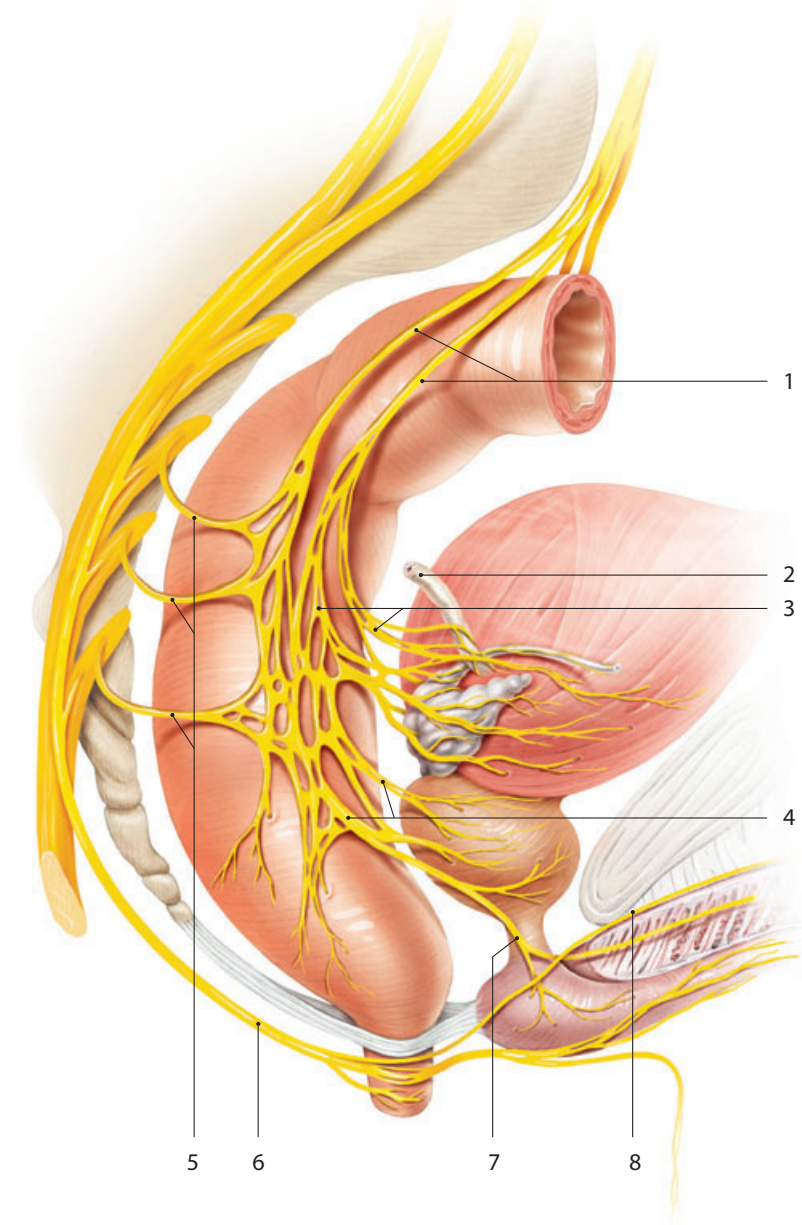


Figure 13

The right-sided pelvic nervous structures in the male (lateral view).

1 Nerve strands of the hypogastric nerve
2 Ureter
3 Inferior hypogastric (pelvic) plexus; ventrocranial portion
4 Inferior hypogastric (pelvic) plexus; dorsocaudal portion
5 Pelvic splanchnic nerves (S2–4)
6 Pudendal nerve
7 Erigent nerve
8 Dorsal nerve of the penis

In the male, the inferior hypogastric (pelvic) plexus is located 1.5–2 cm dorsal and medial to the vesico-ureteric junction [8]. From its ventrocranial portion the plexus releases the branches to the bladder, the terminal ureter, the seminal vesicle and the vas deferens. The pelvic splanchnic nerves, representing the sacral parasympathetic outflow, traverse first of all the dorsocaudal portion of the inferior hypogastric plexus. From this portion the branches extend to the rectum and the prostate gland as far as the corpus cavernosum of the penis, the so-called erigent nerve [9].

Note: To minimize the risk of bladder and sexual dysfunction there should be no preparation dorsomedially to the vesico-ureteric junction, no subtrigonal preparation and no subtrigonal seams. Attention should be paid to stop bleeding in the region of the terminal ureter.

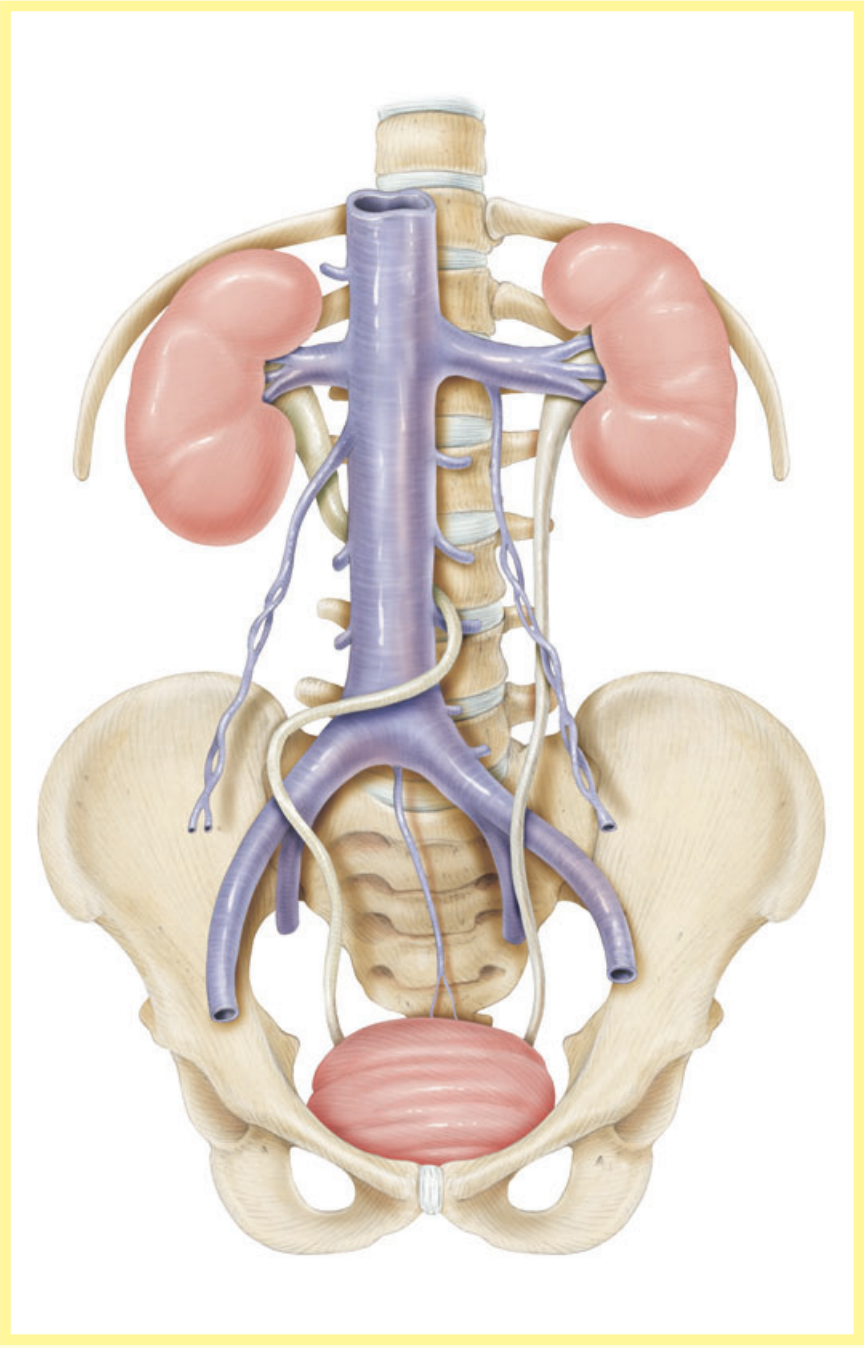
VARIATION OF THE URETER

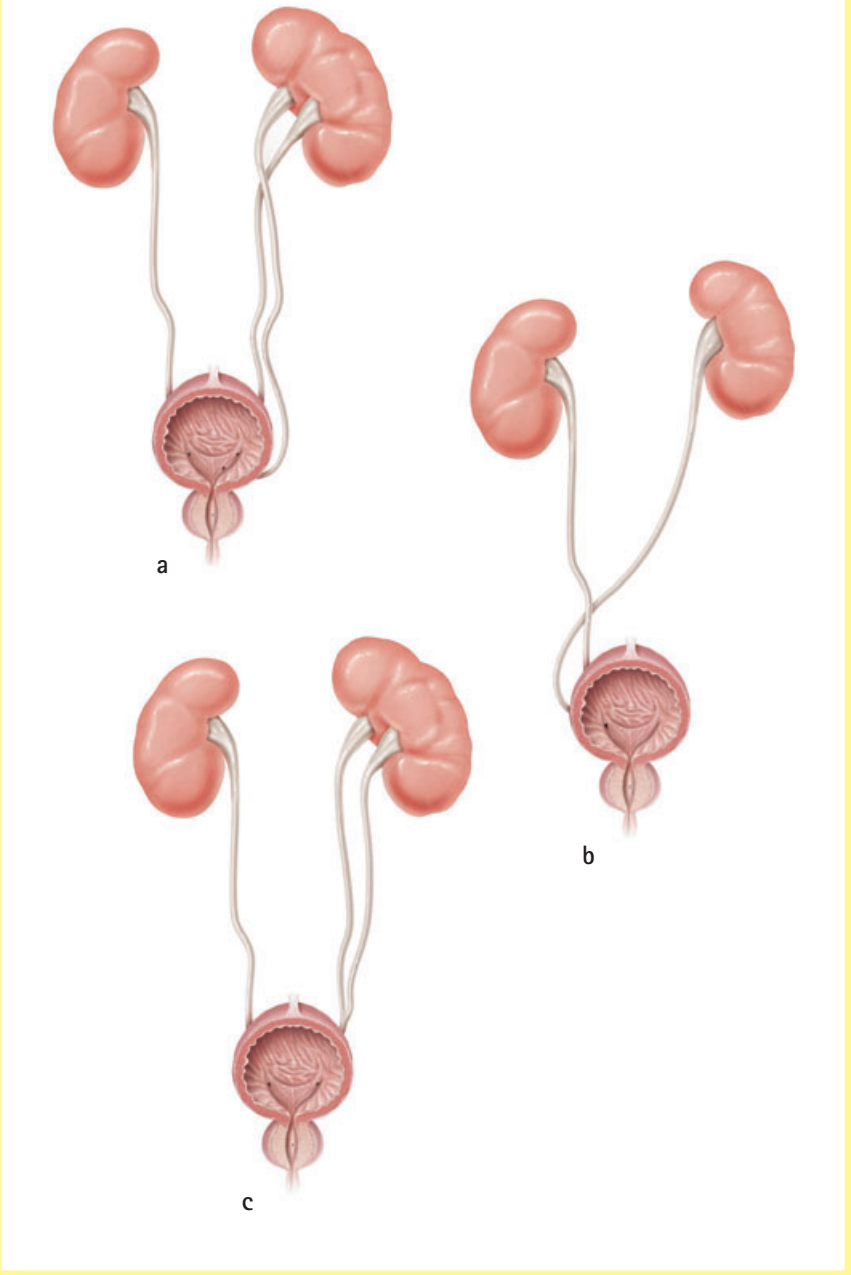
Figure 14

Retrocaval position of the right ureter.

Occasionally, a retrocaval ureter has been encountered on the right side, also known as 'circumcaval ureter'. Retrocaval ureter is one of the rarest congenital anomalies, and can be explained as an abnormality in embryogenesis of the inferior vena cava in terms of abnormal persistence of the right subcardinal vein, a condition in which the ureter deviates medially and passes behind the inferior vena cava, winding about and crossing in front of it from the medial to lateral side. It was first reported by Hochstetter in 1893. The incidence of retrocaval ureter is one in 1500, with a male to female ratio of 3 or 4 to 1. Clinical findings are symptoms of right ureteric obstruction with varying degrees of proximal hydroureteronephrosis.

Note: In cases of adhesiolysis between the ureter and the inferior vena cava, attention is turned to preserving the adventitial vascular plexus of the ureter.





MALFORMATION OF THE URETER

Figure 15

Congenital anomalies of the ureter: **a,** complete reduplication on one side; **b,** unilateral crossed ureter; **c**, unilateral incomplete reduplication of the ureter.

Reduplications of the ureter are of some practical importance; the incidence of a ureteric reduplication is 1 : 100. 'Ureter duplex' denotes complete reduplication of the ureter on one or both sides. The ureter arising from the cranial part of the renal sinus usually opens into the bladder more caudally than normal, while the ureter arising from the lower part of the renal sinus enters the bladder higher than the dystopic ureter (Meyer-Weigert rule). Ureter duplex is due to the presence of two ureteric buds on one or both sides during embryogenesis.

A bifid ureter (ureter fissus) is an incomplete reduplication in its upper part; the two tubes then join and enter the bladder via a single orifice.

Anomalies such as bifurcation or reduplication of the ureter are invariably associated with reduplication of the renal pelvis. When there are two renal pelves they never lie side by side in the renal sinus, but always one above the other, and the cranial one is usually the smaller.

Note: In cases of reduplicated ureter there is a common vascular supply within the ureteric sheath, so that resection of one of the ureters can endanger the blood supply of the remaining ureter and may lead to its necrosis.

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Correspondence: Rosemarie Fröber, Department of Anatomy, Friedrich Schiller University, Jena, Germany.
e-mail: Rosemarie.Froeber@mti.uni-jena.de