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Authors: Weronika Marcinkowska, Mikołaj Malicki, Łukasz Olewnik, Boycho Landzhov, Georgi P Georgiev, Nicol Zielinska

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Morphological variability of the testicular arteries and clinical significance — a comprehensive review

Weronika Marcinkowska[1], Mikołaj Malicki[1], Łukasz Olewnik[2], Boycho Landzhov[3], Georgi P. Georgiev[3, 4], Nicol Zielinska[2]

[1]Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland

[2]Department of Clinical Anatomy, Masovian Academy in Plock, Płock, Poland

[3]Department of Anatomy, Histology and Embryology, Medical University of Sofia, Sofia, Bulgaria

[4]Department of Orthopedics and Traumatology, University Hospital Queen Giovanna-ISUL, Medical University of Sofia, Sofia, Bulgaria

Address for correspondence: Łukasz Olewnik, MD, PhD, Department of Clinical Anatomy, Masovian Academy in Plock, Plac Dąbrowskiego 2, 09–402 Płock, Poland; e-mail: lukaszolewnik@gmail.com

ABSTRACT

The testicular artery is the vessel that provides oxygen-rich blood to the testes. It is also involved in many more processes that play important roles in spermatogenesis such as thermoregulation. As the vessel has a number of anatomical variants, it may be often responsible for difficulties and complications during abdominopelvic surgical procedures. The main aim of the present study is to provide a comprehensive review of literature regarding the anatomical variants of the testicular arteries, focusing not only on their origins but also on the course and number of vessels. It also provides a short review of pathological conditions related to the testicular artery such as aneurysms or testicular torsion and has special value for general surgeons and urologists.

Keywords: testicular artery, anatomical variations, testicular torsion, aneurysm, varicocelectomy

INTRODUCTION

Visceral blood vessel often demonstrate variability and the testicular arteries (TAs) are no exception. In the most dominant anatomical pattern, these vessels branch from the anterolateral surface of the abdominal aorta (AA). The level of their origin is located just inferior to the renal arteries (RAs); it has been estimated that the place of origin corresponds to the height of the second lumbar vertebra [1, 6, 40]. On the right side, the vessel passes anterior to the inferior vena cava (IVC). On the opposite side, the TA courses posterior to the inferior mesenteric vein (IMV). However, there is still a long distance before the arteries reach the main organ they supply, the testes. Following this, the arteries descend towards the pelvis. In this part, the vessels pass along the psoas major muscle. Then, the TAs enter the ipsilateral deep inguinal ring. The TA is located anterior to the genitofemoral nerve, ureter, and external iliac artery. Prior to reaching the respective testis by each TA, these vessels pass via the inguinal canal. In this space, the TA courses with the ipsilateral spermatic cord [31].

The TA is not the only the main source of arterial blood to the testes, the site of sperm cell and hormone production. These arteries also play a pivotal role in thermoregulation needed for effective spermatogenesis. Maintaining the proper temperature is the responsibility of countercurrent heat exchange between the testicular artery and a specialized venous network in the form of the pampiniform plexus, which absorbs the heat carried by the testicular arteries. It also reduces the potentially high mutation rate to which Y chromosomes are susceptible. The mechanism of thermoregulation can be affected by abnormal communication between the testicular vessels. Kumar et al. [25] described a case of arteriovenous communication between the left TA and vein, which can significantly impair the gonadal vascular system. Such a vascular anomaly can lead to blood flow in either direction. The flow of blood from the vein to the artery generates an increase in pressure in the testicular vein, which can consequently cause varicocele. However, the reverse flow, in which venous blood enters the artery, can affect testicular nutrition [4, 20, 25]. The TAs also give off several minor branches to supply the ureter, epididymis and perinephric adipose tissue [31].

Studies on fetuses indicate that 8.8% of the population demonstrate anatomical variations of TAs [10]. Nevertheless, it is difficult to clearly estimate which anatomical pattern is the most common, because variations may relate to origin of the arteries, their course or numbers; as such, literature data varies greatly [22, 37]. A meta – analysis based on 115 articles revealed that anatomical variations of TAs are generally more common on the left side than the right one in humans [31].

The TAs are also involved in urologic disorders. One of the most severe conditions is aneurysm of TA. Its rupture may trigger ischemia of the testis, which impairs their function [34]. Moreover, these vessels are significant in colorectal and renal procedures in male patients, because iatrogenic TA damage can lead to dangerous bleeding [2, 15].

The aim of the article is to collect review the available literature related to anatomical variations of TA. It also proposes its own classification for anatomical patterns described in original studies and case reports. Therefore, this review is of some value for surgeons and urologists. It also describes diseases in which the TAs play a role. Our findings provide a better understanding of the importance of TA in physiological and pathophysiological processes.

EMBRYOLOGY

The embryological origin of the TAs determines differences in origin, course, and branching. The gonadal arteries have a mesonephric origin and their development is related to that of the RAs. However, unlike the kidneys, the testes descend toward the pelvis during development and have three sets of lateral mesonephric arteries: the cranial, middle, and caudalmesenteric arteries [30]. The gonadal artery usually differentiates from one of the caudal arteries, while the superior branches atrophy. In some instances, the lateral caudal and middle mesenteric arteries can persist, resulting in a higher origin of the TAs. In such cases, the cranial lateral mesenteric arteries can give rise to a TA that originates from the suprarenal artery or from a higher level of the aorta. Meanwhile, the medial lateral mesenteric arteries can give rise to a TA that arises from the RA [30, 32].

DIAGNOSTIC

Ultrasonography (US) is the most common non-invasive method employed in the diagnosis of vascular disease and is a well-tolerated imaging modality in the assessment of testicular pathological conditions [47]. US systems consist of a central processing unit (CPU) or computer, transducer, monitor and image storage system [11].

Colour Doppler US examination enables non-invasive assessment of the general condition of abdominal blood vessels without the need for ionizing radiation or contrast. There are two ways to evaluate colour ultrasound imaging: spectral Doppler and colour-flow mode [33]. Spectral Doppler can occur as a pulsed wave or as a continuous wave. In the case of a pulsed wave, a single transducer produces and transmits and then receives the reflected sound waves. Continuous wave Doppler uses two transducers, one which generates and transmits sound waves and another which receives the reflected sound waves [11]. The spectral mode examines the velocity of blood in the arteries. The colour-flow mode, on the other hand, allows assessment of vascularization. This examination shows precisely the blood flow in the vessels. Colour saturation levels relate to blood flow, identifying pathologies in the lumen, wall and surrounding arteries [33].

Doppler ultrasonography plays an increasingly important role in the evaluation of male infertility because of its noninvasiveness and wide availability. It can be used to evaluate the resistive index (RI), indicating testicular parenchymal function, perfusion and microcirculatory function [54]. RI also differentiates between obstructive and non-obstructive azoospermia [41]. The index is measured based on the S-DS. formula, where S represents peak systolic velocity and D means end diastolic velocity. In infertile men, there is a correlation between testicular volume and semen profile, thus RI is a useful clinical parameter because an increase in RI indicates a microcirculatory disorder leading to reduced testicular blood flow [50, 54]. Zolfaghar-Khani et al. [54] indicate that Doppler evaluation of RI of the epididymal and intravesical branches of the TAs can be a valuable and simple diagnostic addition in identifying infertile men with oligoasthenospermia [54]. In cases where sperm counts cannot be determined, ultrasound and colour Doppler examination of the testes can be usedto indirectly assess gonadal function. It has been found that FSH concentration may be inversely correlated with testicular volume and directly with testicular vascularization [47].

Doppler ultrasonography also has diagnostic value in scrotal inflammation by providing perfusion information by determining the RI of the intratesticular and epididymal arteries. In patients with presumed inflammation, it is important to differentiate inflammation from testicular torsion or other causes of scrotal pain via imaging studies [18].

ANATOMICAL VARIATIONS

The literature abounds in original papers aimed at identifying anatomical variations of TAs. The majority are based on classical dissections of cadavers or fetuses. Numerous authors have also proposed their own general classification systems of TA anatomy [4, 10, 24, 28, 36]. Nevertheless, none of them are complete.

In addition, extremely rare anatomical variations of TA, not detected in previous cadaveric studies, have been noted in case reports. Sometimes TA variations are associated with abnormalities of other visceral vessels, such as the RAs, creating complex pictures of anatomical variants that could be a considerable challenge for an operator performing procedures on male abdomen and pelvis [8, 29, 45]. Moreover, in recent years, new original papers based on imaging techniques have been published [3, 7]. Thanks to this, larger groups of patients could be examined for TA variability.

A description of TA anatomical variability should include several aspects: origin, course of the vessel, and number of arteries. Each point is reviewed below.

Place of testicular artery origin

Gonadal arteries most frequently arise from the front of the abdominal aorta at the level of the second lumbar vertebra. Although the anatomical features of the gonadal vessels are relatively consistent, some developmental and anatomical differences have been noticed on both sides of the body with different frequencies reported by different authors. Such variations have involved high origins in the AA, and in other arteries, such as the RA [14, 31]. An abnormal onset of the TA from the AA was observed by Pai et al. [36] and Ciçekcibaşi et al. [10], where the TA had a more superior aortic origin at the level of the RA. An origin from the main RA and associated arteries, named an aberrant gonadal artery, is also frequently described in the literature [4, 10, 14, 28, 36]. Much more rarely observed is TA arising from the inferior epigastric artery [28]. The literature also reported a case of bilateral low origin of the TA from the abdominal aorta, at a level corresponding to the third lumbar vertebra. The right testicular artery originated from the abdominal aorta, just above the origin of the inferior mesenteric artery, and the left artery emerged from the left lateral edge of the aorta. This case, due to the low origin of the TA, might lead to iatrogenic trauma during surgery in the lower abdomen [5].

Gupta et al. [14] reported a rare but clinically important case, especially in abdominal and urogenital surgical procedures, in which the left TA originates from the left accessory RA and passes through a hiatus in the left renal plexiform vein [14]. Ciçekcibaşi et al. [10] described cases in which the TA arises from either the right or left inferior polar RA. The occurrence of such an origin is a contraindication for percutaneous treatment of pielo-ureteral junction syndrome, because of the risk of serious hemorrhage [44]. The presence of an aberrant gonadal artery is of great significance to surgeons operating near the renal pedicle or in the retroperitoneal space, which include partial or total nephrectomy and kidney transplantation [14].

Number of testicular arteries

The most common quantitative variation is the presence of a double TA [31]. Among the cases reported in the literature, both arteries arise from the AA, or one artery originates from the AA and the other from another artery [4, 10, 24, 36, 52]. Asala et al. [4] described two cases of the presence of an accessory right TA, which had a high origin and extended from the aortic surface at the level of the superior mesenteric artery [4]. A similar case of TAs departing from the right side of the aorta was described by Ciçekcibaşi et al. [10] who also reported two cases in which one of the arteries departed from the AA and the other from the suprarenal artery [10]. Pai et al. [36] describe the occurrence of double TAs on the right side: one lateral and one medial. The lateral TA diverged from the upperprehilar right RA, while the medial TA originated on the anterior surface of the AA, as a common trunk with the inferior suprarenal artery and the renal capsular artery [36]. Sometimes, the TA can be absent. The gonads then receive oxygenated blood through the vesicle/prostatic arteries. Kotian et al. [24] reported two such cases.

Variations in the course of testicular arteries

The most common course variation is a TA arched over the ipsilateral renal vein. Gupta et al. [14] describe a case of arched TA (Luschka), where the left TA, after departing from the AA, passes behind the left renal vein and then arched at its upper border. Such a course is more commonly observed on the left side, due to the anatomically superior position of the left kidney relative to the right. If the kidney ascends higher during development, carrying the renal vein higher than the TA, this determines the arched course of the TA around the vein. The occurrence of an arched TA has clinical implications, because such a course of the artery can lead to compression of the renal vein and can progress to renal vascular hypertension. Consequently, it can result in swelling of the testicular vein leading to varicocele [14].

TA passing through a vascular hiatus in the renal vein is a very rare case, but of major clinical importance from both surgical and physiological perspectives. Such an abnormal course can lead to TA entrapment and testicular degeneration, but also to retrograde blood flow from the renal vein to the TA and the development of varicocele. In addition, the presence of a vascular hiatus in the renal vein might lead to compression of the vein, reduced blood flow and the development of nutcracker syndrome. Therefore, knowledge of the course of the TA in connection with the renal vein is important for surgeons because of the possibility of avoiding complications especially during transplantation, renal surgery, vascular surgery and gonad surgery [35].

Clinical significance

The anatomy and variability of the TA is an important consideration in new surgical procedures in the retroperitoneal space [7]. The TA has a major role in orchidectomy. It is ligated proximal to the spermatic cord, which is critically important for good hemostasis. However, if the TA is ligated incorrectly it can lead to life-threatening haemorrhage into the retroperitoneum [16].

The gonadal artery is also susceptible to injury during colorectal surgery due to its anatomical proximity to the colon and rectum. Hsu et al. [15] report the incidence of injury to the gonadal artery during colorectal surgery to be 3.61%, more common than ureteral and bladder injuries [15]. Variations in the course of the gonadal arteries can sometimes affect vascular and developmental anomalies of the kidney. This is due to the renal and gonadal vessels sharing a common origin from the lateral mesonephric branches of the dorsal aorta [14]. Therefore, any variations in the origin, number or course of the TA can increase the risk of renal ischemia during surgery [22].

Aneurysm

An aneurysm is a localized, pathological dilatation of a blood vessel resulting from the weakening and destruction of its wall [17]. Aneurysms have been divided into two main types. True aneurysms, i.e. with a wall, include all layers of vascular structure; they are related to arterial fibrodysplasia, polyarteritisnodosa, vasculitis, systemic lupus erythematosus. The second type is pseudoaneurysms: these have a fibrous sac without any endothelium or vascular wall structure. Similarly, “false aneurysms” develop as a result of blunt or penetrating injuries. However, the most common cause is iatrogenic trauma such as biopsy. The exact pathophysiology of aneurysms is still unclear [17, 39]. Their most important risk factors are atherosclerosis, syphilitic arteritis, inflammation, infection, and trauma. They commonly occurs in the aorta and in the cerebral, coronary, femoral, and popliteal arteries [34]. TA aneurysms are uncommon and usually arise from trauma, inflammation, and infection. Most occur in an intratesticular location, and patients present with scrotal pain or a painless palpable mass in the inguinal region. There is no standard treatment for TA aneurysms due to their rare occurrence. In the literature, when the aneurysm grows or there is severe scrotal pain, surgical excision was performed [53].

Zicherman et al. [53] report the case of a 91-year-old male presenting with discoloration of the left scrotum and the presence of a painful, palpable nodular mass in the left groin on physical examination. Sonography of the left scrotum was performed, revealing the presence of a hypoechoic mass. In addition, colour Doppler imaging detected a pulsatile flow in the center of the mass, which was consistent with an aneurysm. CTA and MRI confirmed the presence of a mass in the left inguinal region with an aneurysmal protrusion of the TA. The authors hypothesize that the aneurysm was due to undiagnosed trauma or as a result of advanced atherosclerosis. This case demonstrates that vascular status should be considered in the evaluation of masses located in the inguinal region [53].

Verma et al. [51] describe a rare case of spontaneous aneurysm from an anomaly of the TA. A 29-year-old male presented with a benign, dull, localized epigastric pain. Ultrasonography revealed a vascular lesion in the form of a pulse wave. A CTA was performed, which showed an abnormal origin of the left TA from the hilar segment of the RA, and the presence of an aneurysm in the proximal portion of the left TA.As, in this case, the gonadal artery originated from the hilar segment of the left RA, endovascular treatment would be technically difficult, and due to the fact that the aneurysm was small and the patient had mild pain, he was left for observation [51].

Ohmori and Isokawa [34] report a case of 51-year-old male who presented with a non-painful, hard and mobile mass within the seminal vas deferens in the right scrotum. Ultrasound confirmed its presence, and MRI showed a circular shadow. Due to the progressive enlargement of the mass, it was decided for resection, which revealed the possible presence of a vessel on the central and peripheral sides. Pathological examination of the removed tissue indicated the absence of an inner and outer elastic membrane, a thick muscular layer, and a tunica intima with a wavy structure. Therefore, the resected specimen was considered to show arterial dilatation and testicular aneurysm was diagnosed [34].

Parker and Nangia [38] report a case of TA pseudoaneurysm. A 34-year-old male presented with right-sided orchialgia. Physical examination revealed swelling and hardening of the right testicle without involvement of the periventricular structures. Ultrasonography of the scrotum showed an area of hypoechogenicity with a 1 cm diameter central focus that manifested an arterial waveform with alternating flow reversal, suggesting the presence of a pseudoaneurysm [38].

Dee et al. [12] report a case of 42-year-old male, who suffered from blunt scrotal trauma. The patient presented with swelling and pain in the left scrotum that was increasing. Sonographic examination revealed an intratesticular hematoma, and the circular anechoic structure present was consistent with a pseudoaneurysm [12].

Testicular torsion

Testicular torsion is a vascular condition and a common urological condition involving torsion of the seminal vas deferens, occurring at a rate of one in 4,000 men under the age of 25 years [13]. The consequence of testicular torsion is obstructed blood supply to the testicle, which can lead to testicular atrophy. For this reason, to avoid ischemia and infarction of the testicle, the patient should be treated surgically immediately [13, 21].

The occurrence of testicular torsion mainly affects the neonatal period and puberty [48]. In neonates, the predominant type is extravaginal torsion, which occurs during testicular descent into the scrotum and involves torsion of the entire seminal vas deferens including the umbilicus along with the processus vaginalis. The result is necrosis and impaired blood flow through the testicles and epididymis. Torsion in newborns can occur both prenatally and in the early postnatal period [48]. If torsion occurs before birth the characteristic clinical sign in newborns is the presence of blue, insensitive and hard masses in the scrotum. In contrast, torsion after birth manifests as painless scrotal swelling with acute inflammation and erythema. Pogorelić et al. [42] report the case of a male neonate who presented with bilateral testicular torsion. The patient had diffuse swelling and redness of the scrotum and palpable tenderness of the testicles at birth. Examination performed revealed an extraperitoneal torsion of the right testicle with apparent gangrene of the right testicle and an extraperitoneal torsion of the left testicle [42].

However, during puberty, intravaginal torsion is predominant, in which there is a twisting of the seminal vagina within the tunica vaginalis. The most common cause of this type of torsion is congenital malformations of the processus vaginalis. In this case, there is a bell-clapper testicle, which is caused by an abnormal fixation of the tunica vaginalis, which completely surrounds the testicle and epididymis. Such a testis is oriented more horizontally, which promotes its increased mobility [48, 49]. Lorenzo et al. [27] report a case of 15-year-old boy with bilateral testicular torsion. The patient presented with pain, swelling, and tenderness of the left scrotum. Colour Doppler examination revealed left testicular torsion, lack of vascular flow, and heterogeneous testicular structure. In contrast, the right testis showed no abnormality. After two hours, the patient developed sudden right scrotal pain, so the examination was repeated, which revealed intracavernosal torsion of the right testis and torsion of the left testis with fixed necrosis [27].

Torsion of the vas deferens can consequently lead to ischemia-reperfusion injury of the testis, the severity of which depends mainly on the duration of torsion and the degree of torsion. Such damage can result in infertility, which is related to hypoxia and changes in blood flow through the testis [21]. Kuremu [26] describe a case of a patient who developed bilateral testicular torsion. A 20 year-old male presented to the hospital with gradual decrease in both testicles and erectile problems. Previously, the patient suffered from sudden pain and swelling of the right scrotum, which was not properly diagnosed, and the left testicle was also injured after a period of time. This is due to the fact that misdiagnosis in addition to testicular loss associated with unilateral torsion also leads to immunological damage to the opposite testicle [26].

Testicular artery in varicocelectomy

A varicocele is an abnormal dilatation of the internal spermatic vein and the pampiniform venous plexus within the spermatic cord. The formation of varicocele can be caused by elevated testicular temperature, increased venous pressure, hypoxia, oxidative stress, endocrine disruption, and reflux of toxic metabolites from the adrenal glands or kidneys [9]. Varicocele is the most common correctable cause of male infertility due to the fact that it can induce progressive testicular damage resulting in hypotrophy, impaired sperm production, and decreased semen quality [9, 19]. Patients with varicocele are usually asymptomatic, although some patients complain of discomfort, pain, and swelling of the scrotum.

Treatment is based on ligation of the internal and external spermatic veins with preservation of arterial blood flow through the testicle, lymph vessels, and vas deferens. In adults, it aims to improve semen parameters and current fertility status, while in young adults, treatment focuses on preventing testicular hypotrophy and ensuring future fertility [9, 23]. The primary treatment options are percutaneous vein embolization and surgical repair. In the latter, the TA has a role. Varicocelectomy can be performed by microsurgical subinguinal, inguinal, abdominal and laparoscopic methods. The most common postoperative complications are varicocele recurrence and hydrocele formation. These are related to the surgical technique and the disposition of the TA [43]. It has been found that sparing the TA provides a lower incidence of hydrocele, but a higher recurrence rate and prolonged surgery time [43]. On the other hand, both approaches, i.e. with and without artery preservation, yielded similar results in terms of semen quality, serum sex hormone levels, testicular stromal atrophy, and spontaneous pregnancy rates [43, 46]. Therefore, it is recommended to ligate the artery and vein together to reduce the recurrence rate, and to make the operation easier and shorter [43].

CONCLUSIONS

Anatomical knowledge of the TA is very important for performing abdominal and pelvic surgical techniques. Information about the origin is surgically relevant during procedures such as nephrectomy and kidney transplantation, due to the possibility of occurrence of abberant TA. Surgeons need to be aware of the possibility of morphologic variants of TA to prevent gonadal oxygenation from being impaired during surgery, resulting in testicular atrophy.

Article information and declarations

Authors' contributions

Weronika Marcinkowska — project development, data collection and management, data analysis and manuscript writing. Mikołaj Malicki — data collection, data analysis and manuscript editing. Łukasz Olewnik — data collection, data analysis and manuscript editing. Boycho Landzhov — data collection, data analysis and manuscript editing. Georgi P. Georgiev — data collection, data analysis and manuscript editing. Nicol Zielinska — data collection, data analysis and manuscript editing.

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Conflict of interest

The authors declare that they have no competing interests.

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