REVIEW

Variations of the Testicular Artery and Vein: A Meta-Analysis with Proposed Classification

TOM. J. NALLIKUZHY, S. S. S. N. RAJASEKHAR ,* SABIN MALIK, DHARMARAJ W. TAMGIRE, PHOEBE JOHNSON, AND K. ARAVINDHAN

Department of Anatomy, Jawaharlal Institute of Postgraduate Medical Education & Research (JIPMER), Dhanvantri Nagar, Gorimedu, Puducherry 605006, India

Variations of testicular vessels are more common than supposed. The testicular artery varies because of abnormal regression of the lateral mesonephric arteries in the fetus, whereas variations in the testicular vein are due to abnormalities in the involution of the intersubcardinal anastomosis. Such variations are usually found incidentally during surgical procedures around the renal pedicle and they often lead to complications. Several authors have attempted to classify them. However, these attempts have not been comprehensive. Therefore, the aim of this study is to provide a simple yet comprehensive classification of variations of the testicular vessels. The PubMed database was searched using keywords pertaining to the testicular vessels. The results were subjected to the Anatomical Quality Assessment (AQUA) tool analysis and were screened for appropriateness for inclusion in this study. The screening procedure yielded 31 original articles, 83 case reports, and 1 review article. Both testicular arterial and venous variations were more common on the left side (20.73% and 24.61%) than the right (12.69% and 18.4%, respectively). We classified the testicular arteries on the basis of their number (N), site of origin (O), and course (C). Similarly, the testicular veins were classified on the basis of their number (N) and site of drainage (D). The proposed classification facilitates identification, understanding, and reporting of variations of the testicular vessels by radiologists. It will also help surgeons to enhance the quality of their treatment. Clin. Anat. 00:000–000, 2018.

Key words: aberrant; arterial; gonadal; multiple; testicular; variation; vascular; venous

INTRODUCTION

Testicular artery (TA) originates as a lateral branch of the abdominal aorta (AA) inferior to the level of origin of the renal arteries (RA) (Fig. 1a). On the right side, the artery passes anterior to the inferior vena cava (IVC), while on the left, it passes posterior to the inferior mesenteric vein. It descends inferolaterally toward the pelvis along the psoas major muscle, under cover of the parietal peritoneum, and then enters the ipsilateral deep inguinal ring. Here, it lies anterior to the genitofemoral nerve, ureter, and external iliac artery. After entering the inguinal canal, it travels with the ipsilateral spermatic cord to reach the corresponding testis. During this course the TA gives off numerous branches to supply the perinephric fat, ureter, head, and body and tail of the epididymis, and sometimes additional TAs. Upon reaching the testis, branches of the artery enter the tunica albuginea through the mediastinum of the testis. They subsequently ramify in the tunica vasculosa before reaching the point of distribution (Goldstein and Mehta, 2016). Cauldwell and Anson observed that in most cases the

*Correspondence to: S.S.S.N. Rajasekhar, Associate Professor, Department of Anatomy, JIPMER, Puducherry 605006, India. E-mail: sekhar5883@gmail.com

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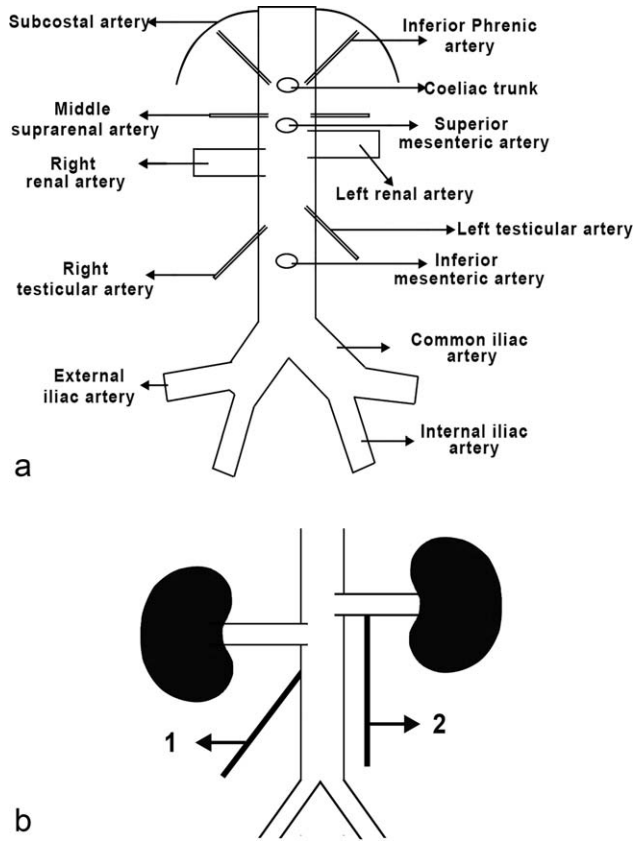

Fig. 1. (**a**) Branches of the abdominal aorta (AA). (**b**) Normal drainage of the testicular veins (TVs): 1, the right TV draining into the inferior vena cava (IVC); 2, the left TV draining into the left renal vein (RV).

TA originates from the AA at the level of the second or third lumbar vertebra, just below the level of origin of the RA (Anson and McVay, 1936; Cauldwell and Anson, 1943). Numerous authors have reported variations in the origin and course of the TA, and a few such as Lippert and Pabst (1985), Çiçekcibaşi et al. (2002), Notkovich (cited in Pai et al., 2008), Kotian et al. (2016), Radojevic and Stolic, and Machnicki and Grzybiak (both cited in Kayalvizhi et al., 2017) have classified these variations.

The veins draining the testis, epididymis, and vas deferens form superficial and deep venous networks. The superficial network primarily drains the scrotum and terminates in the internal or external pudendal veins. The deep network has three components: anterior, middle, and posterior. The anterior component arises as small veins from the testis and the anterior aspect of the epididymis. The veins from the anterior component give rise to around ten branches, which anastomose to form a mesh-like complex of large veins known as the pampiniform plexus. The veins from the vas deferens form the middle component and those from the cremaster muscle form the posterior component. The veins of the pampiniform plexus ascend in the spermatic cord along with the TA and fuse to form three to four veins. As they reach the internal inguinal ring they unite to form two veins. Finally, they join to form a single testicular vein (TV) (MacLennan and Hinman, 2012). The right TV drains into the IVC and the left into the left renal vein (RV) (Fig. 1b) (Goldstein and Mehta, 2016).

Venous anomalies are frequent and diverse, so it is practically challenging to classify the variations of the TV. Asala et al. (2001) classified these variations on the basis of their number. Earlier classifications were based on the presence or absence of valves and the angle at which the vein opens into the parent vein (the IVC on the right side and the RV on the left). Previous classifications of the testicular vessels were either incomplete or based on very few subjects. In this era of individualized medicine, identification of variations is essential before any procedure is performed. This requires a thorough knowledge of the variations of the testicular vessels. In this review, we propose a new classification for the variations of the testicular vessels based on data collected from various studies. This simple yet comprehensive classification will facilitate reporting of the variations, which can lead to a better outcome for patients.

MATERIALS AND METHODS

The PubMed database was searched from March 2017 to February 2018 using the combinations of keywords "duplicated," "double," "multiple," "arched," "arching," "hypoplastic," "trifurcation," "triplicated," "looped," "looping," "testicular," "gonadal," "artery," "veins," and "vessels."

RESULTS

The above search yielded 1,007 results. Removal of duplicate articles left 477 hits. All the articles depicting variations of the testicular vessels were included. Exclusion of unrelated and non-English articles resulted in 45 hits. Cross-referencing of these 45 hits identified 123 articles, which included 31 original articles, 91 case reports and 1 review article.

Eligibility Criteria

All the articles obtained were analyzed by two independent reviewers using the Anatomical Quality Assessment (AQUA) tool (Henry et al., 2017). The first reviewer gave a low bias for 112 articles, high bias for seven and an unclear response to four. The second reviewer gave a low bias for 110 articles, high bias for six and an unclear response to 7. The reviewers disagreed about 16 articles. They discussed the points of contention and a consensus was reached to exclude 8 articles and include 115 in this meta-analysis.

Statistics

The prevalence of variations in the testicular vessels was calculated from the data in the original articles. There were more variations in the TA on the

TABLE 1. Variations of the Testicular Arteries (TAs) Based on the Number (Number of Cases Reported)

Right	No: of cases	Left	No: of cases
Double TA		Double TA	
Asala et al. (2001)	2	Kotian et al. (2016)	2
Çiçekcibaşi et al. (2002)	3	Notkovich (1955)	1
Notkovich (1955)	1	Cauldwell and Anson (1943)	17
Cauldwell and Anson (1943)	12	Wadhwa and Soni (2010)	1
Pai et al. (2008)	1	Petru et al. (2007)	4
Total	19		25
Absent TA		Absent TA	
Kotian et al. (2016)	2	Kotian et al. (2016)	2
Nordmark (1977)	1	Nordmark (1977)	1
Total	3		3

left side (242/1,167, 20.73%) than the right (156/1,229,12.69%) . The TA had an abnormal origin in 68/1,229 (5.53%) cases on the right side and 79/1,167 (6.77%) on the left. It originated from the AA at a different level from normal in 26 cases, nine on the right side (9/1,229; 0.73%) and 17 on the left (17/1,167; 1.45%). Various authors reported the origin of the TA from the RA and its associated arteries. In 114 cases, the TA originated from the RA and its associated branches; among these, 56 (56/1,229, 4.55%) were on the right side and 58 (58/1,167, 4.97%) on the left.

Double TAs were more common on the left side than the right. They were present in 25/1,167 (2.14%) cases on the left. Among these, 14 (1.19%) had both arteries arising from the AA; one artery originated from the AA and another from a separate artery in nine cases (0.77%); and both arteries originated from vessels other than the AA (both from the RA) in two cases (0.17%). On the right side, 19/1,229 (1.54%) cases showed a double TA. Among these, both the arteries originated from the AA in nine cases (0.73%) and one from the AA and the other from a different artery in 10 (0.81%). None of the cases had both arteries originating from a vessel other than the AA. Very few authors (0.2%) have reported absence of the TA.

Arching of the TA was also more common on the left side (141/1,167, 12.08%) than the right (65/1,229, 5.28%). The right TA followed a retrocaval course in six cases (6/1,229, 0.49%). The prevalence of these TA variations is summarized in Tables (1–3).

Variations of the TV were also more common on the left side (206/837, 24.61%) than the right (152/826, 18.4%). More than 20% of cases showed multiple TVs on the left side (198/8,837, 23.65%). Of these, 139 (16.61%) were double veins, 18 (2.15%) were triple, and one (0.12%) was quadruple. Forty cases were reported as multiple veins but the numbers of veins were not stated. On the right side, 66 cases had multiple veins (66/826, 7.99%). Among these, 34 (4.12%) were double veins, four (0.48%) were triple, and 28 cases were reported as multiple veins (number not stated). In contrast to the other parameters, variations in the drainage of the TV were more common on the right side. In 63 cases (63/826,

TABLE 2. Variations of the Testicular Arteries (TAs) Based on the Site of Origin (Number of Cases Reported)

Right	No of Cases	Left	No of Cases
From abdominal aorta (AA)		From AA	
Çiçekcibaşi et al. (2002)	3	Kotian et al. (2016)	14
Mohandas et al. (2014)	1	Pai et al. (2008)	3
Kotian et al. (2016)	4		
Önderoğlu et al. (1993)	1		
From renal artery (RA)and accessory branches		From RA and accessory branches	
Mohandas et al. (2014)	1	Gupta et al. (2011)	2
Asala et al. (2001)	5	Kotian et al. (2016)	4
Pai et al. (2008)	4	Adebisi and Singh (2000)	7
Shoja et al. (2007)	11	Cauldwell and Anson (1943)	19
Cauldwell and Anson (1943)	22	Wadhwa and Soni (2010)	1
Wadhwa and Soni, (2010)	2	Petru et al. (2007)	13
Petru et al. (2007)	3	Shoja et al. (2007)	3
Gupta et al. (2011)	2	Mamatha et al. (2015)	4
Bordei et al. (2004)	3	Çiçekcibaşi et al. (2002)	3
Mamatha et al. (2015)	1	Pai et al. (2008)	2
Çiçekcibaşi et al. (2002)	2		
From other vessels		From other vessels	
Çiçekcibaşi et al. (2002)	2	Çiçekcibaşi et al. (2002)	1
Mamatha et al. (2015)	1	Wadhwa and Soni (2010)	2
		Mamatha et al. (2015)	1
Total	68		79

TABLE 3. Variations of the Testicular Arteries (TAs) Based on the Course (Number of Cases Reported)

Arching TA					
S no:	Right	No: of cases	S no	Left	No: of cases
1.	Notkovich (1955)	2	1.	Gupta et al. (2011)	1
2.	Notkovich (Nathan et al., 1976)	14	2.	Pick (Grine and Kramer, 1981)	45
3.	Adebisi and Singh (2000)	29	3.	Notkovich (1955)	8
4.	Grine and Kramer (1981)	19	4.	Naito et al. (2006)	4
5.	Önderoğlu et al. (1993)	1	5.	Notkovich (Nathan et al., 1976)	38
			6.	Adebisi and Singh (2000)	27
			7.	Wadhwa and Soni (2010)	1
			8.	Grine and Kramer (1981)	17
	Total	65		Total	141
S no:	Retrocaval course of right TA				No: of cases
1.	Notkovich (1955)				2
2.	Wadhwa and Soni (2010)				3
3.	Önderoğlu et al. (1993)				1
	Total				6

7.63%), the right TV drained into the right RV instead of the IVC, and in 23 cases (23/826, 2.78%) it drained into the confluence of the IVC and the right RV. In five cases (5/837, 0.59%), the left TV drained into the IVC. These TV variations are summarized in Tables 4 and 5.

DISCUSSION

Variations in the testicular vessels with a review of the literature based on origin, number, course, abnormal branches and site of drainage, along with embryological basis and clinical importance, are discussed below.

VARIATIONS IN THE TESTICULAR ARTERY

The number, origin, or course of the TA can vary. Tubbs et al. (2016) discussed the variations in the origin and course of gonadal arteries in "Bergman's Comprehensive Encyclopedia of Human Anatomic Variation." Variations in origin included a high origin from the AA, origin from other arteries such as the RA, and multiple gonadal arteries (double TA). The right TA originated from the RA in 2.63% of cases and the left TA originated from it in 5.26%. Regarding the double TA on the right side, both the TAs (upper and lower) originated from the AA in 10.52% of cases, and the upper TA originated from the RA and the lower TA from the AA in 2.63%. The upper TA originated from the accessory RA and the lower TA from the AA in 2.63%. Regarding the double TAs on the left side, the upper TA originated from the RA and the lower TA from the AA in 7.89%. In 2.63% of cases, there was a high origin of the right TA from the AA. Variations in the course included a retrocaval course of the right gonadal artery (13.15%), an arching gonadal artery, and the gonadal artery passing through a bifid RV (Tubbs et al., 2016).

TABLE 4. Variations of the Testicular Veins (TV) Based on the Number (Number of Cases Reported)

	Right			Left	
Sl. No.	Double TVs	No of cases	Sl. No.	Double TVs	No of cases
1.	Kara et al. (2012)	2	1.	Kara et al. (2012)	13
2.	Shafik et al. (1990)	2	2.	Pai et al. (2008)	1
3.	Comhaire et al. (1981)	11	3.	Shafik et al. (1990)	1
4.	Favorito et al. (2007)	15	4.	Comhaire et al. (1981)	52
5.	Malar (2016)	1	5.	Favorito et al. (2007)	23
6.	Gupta et al. (2015)	2	6.	Malar (2016)	2
7.	Lalwani et al. (2017)	1	7.	Gupta et al. (2015)	12
			8.	Sofikitis et al. (1993)	26
			9.	Barber et al. (2012)	4
			10.	Lalwani et al. (2017)	5
	Triple TVs			Triple TVs	
1.	Comhaire et al. (1981)	4	1.	Comhaire et al. (1981)	15
			2.	Favorito et al. (2007)	2
			3.	Sofikitis et al. (1993)	1
	Quadruple TVs			Quadruple TVs	
				Favorito et al. (2007)	1
	Multiple TVs			Multiple TVs	
1.	Barber et al. (2012)	3	1.	Lechter et al. (1991)	40
2.	Lechter et al. (1991)	25			
	Total	66		Total	198

TABLE 5. Variations of the Testicular Veins (TVs) Based on the Site of Drainage (Number of Cases Reported)

Right TV					
S no:	to right renal vein (RV)	No: of cases	S no:	to confluence of right RV and inferior venacava (IVC)	No: of cases
1.	Kara et al. (2012)	13	1.	Comhaire et al. (1981)	13
2.	Comhaire et al. (1981)	24	2.	Favorito et al. (2007)	10
3.	Favorito et al. (2007)	2			
4.	Malar (2016)	1			
5.	Gupta et al. (2015)	6			
6.	Barber et al. (2012)	8			
7.	Rivington (Ahlberg et al., 1966)	1			
8.	Ahlberg et al. (1966)	3			
9.	Asala et al. (2001)	2			
10.	Phalgunan et al. (2012)	2			
11.	Lalwani et al. (2017)	1			
Total		63	Total		23
S no	Left TV draining into IVC				No of cases
1.	Comhaire et al. (1981)				1
2.	Sofikitis et al. (1993)				1
3.	Barber et al. (2012)				2
4.	Lalwani et al. (2017)				1
	Left TV draining to Accessory RV				
1.	Comhaire et al. (1981)				3
Total					8

Other authors have also reported numerous variations of the TA, and some have attempted to classify them. In 1964, Radojevic and Stolic proposed a classification into four types on the basis of the origin of the arteries. Type I: TA directly originating from the AA; type II: TA originating from the RA and its associated arteries; type III: TA originating from the middle suprarenal artery; and type IV: TA originating from the AA just below the level of origin of the RA, to pass superiorly and arch over the RV (Kayalvizhi et al., 2017). Kotian et al. (2016) also classified variant TAs on the basis of origin as (a) normal origin, (b) high origin from the AA, (c) origin from the RA, and (d) low origin from the AA. Machnicki and Grzybiak grouped the variant TAs as (a) single TA from the AA, (b) single TA from the RA, (c) double TAs from the AA, and (d) double TAs from both AA and RA (Kayalvizhi et al., 2017). Çiçekcibaşi et al. (2002) described four types of variant TA. Type I: from the suprarenal artery; type II: from the RA; type III: high origin from the AA; and type IV: duplicated arteries. On the basis of the course of the TA and its relationship to the RV, Notkovich in 1956 had classified TAs into three types. Type I: the artery passes laterally and downwards after arising from the AA below the level of the RV; type II: the artery passes anterior to the RV after arising from the AA above the RV; type III: the artery passes upward to arch over the RV after its origin from the AA below the level of the RV (Pai et al., 2008). Lippert and Pabst (1985) classified TAs on the basis of origin and course. Variations in origin were classified as (a) arteries originating only from the AA (15%), (b) arteries originating from the RA (17%), and (c) arteries originating from other vessels (<1%). Among the TAs originating from the AA, the following observations were made: in <0.1% of cases a common trunk originated from the AA, which later divided into right and left TAs. In <1%, one TA has two or more joining roots to the AA. In 8%, two TAs originated from the AA on the left side. In 4%, two TAs originated from the AA on the right side. In 2%, there were two TAs on the right side and two on the left originating from the AA. In <1%, three TAs originated from the AA on one side (more commonly on the left). Among the TAs originating from the RA, the following observations were made. The right TA originated from the right RA in 6%. The left TA originated from the left RA in 4%. Both TAs originated from the RAs of their respective sides in 4%. The TAs on one side had a dual origin (from the AA and the RA) in <1% of cases. In <1%, two TAs originated on one side (one from the AA and the other from the RA). In 1%, two TAs originated from the right RA. In <1%, two TAs originated from the left RA. In 1%, two TAs originated on both sides from the RAs. In <1%, TAs arose from other arteries such as the lumbar, common iliac, internal iliac, and inferior epigastric.

In 20% of cases, the TAs originated from the AA and coursed dorsal to the IVC and ventral to the right RV. In some rare cases, TAs arching over the RA were also reported (Lippert and Pabst, 1985).

VARIATIONS BASED ON THE NUMBER OF ARTERIES

Multiple Testicular Arteries

Most cases of multiple TAs were double TAs. Among these, either both arteries originated from the AA or one artery originated from the AA and the other from a different artery. Sometimes the double TAs originated from an artery other than the AA. Tubbs et al.

TABLE 6. Variations Based on Number of the Testicular Arteries (TAs) Reported by Various Authors

No of arteries		Right	Left
Double	Both from Abdominal aorta (AA)	Cauldwell and Anson (1943), Notkovich (1955), Asala et al.(2001), Çiçekcibaşi et al.(2002), Odekunle and Uche-Nwachi (2007), Fating (2015)	Cauldwell and Anson (1943), Notkovich (1955), Loukas and Stewart (2004), Kayalvizhi et al.(2011), Rao et al. (2012), Paraskevas et al. (2014), Kotian et al. (2016)
	One from AA; one from another artery{given in brackets}	Cauldwell and Anson (1943) {renal artery (RA)}, Çiçekcibaşi et al. (2002) {suprarenal}, Rusu (2006) {superior RA}, Nayak et al. (2007) {upper prehilar RA}, Pai et al. (2008) {upper prehilar RA}, Gurses et al. (2009) {lower hilar RA}, Paraskevas et al. (2014) {RA}, Mazengenya (2016) {subcostal}, Nallikuzhy et al. (2017) {RA}	Cauldwell and Anson (1943) {RA}, Sekiya et al. (1997) {inferior accessory RA}, Petru et al. (2007) {inferior accessory RA & segmental RA}, Soni and Wadhwa (2010) {inferior RA}, Wadhwa and Soni (2010) {inferior RA}, Filipovic et al. (2012) {accessory RA}, Tadipi et al. (2015) {lower prehilar RA},
	Both from another artery	Bergman et al. (1992) {RA &inferior polar RA}	Deepthinath et al. (2006) {RA & accessory RA}, Petru et al. (2007) {both RA-2 cases}
	Single trunk dividing into two (artery of origin)	Tanyeli et al. (2006) {RA}, Mao and Li (2017) {AA}	Gerard{AA}(Cauldwell and Anson, 1943), Rusu (2006) {AA}, Kotian et al (2016) {AA}
Absent		Nordmark (1977), Kotian et al. (2016), Thangaraj and Vishali (2017)	Nordmark (1977), Kotian et al. (2016)

(2016) reported double gonadal arteries in 17% of cases. Among these, the medial gonadal vessel originated from the AA, whereas the lateral gonadal vessel originated from the AA or the RA (Tubbs et al., 2016). Tanyeli et al. (2006), Rusu (2006), Kotian et al. (2016), and Mao and Li (2017) reported cases where the artery originated as a single trunk, later bifurcating. The artery originated from the right RA in one case (Tanyeli et al., 2006) and from the AA in the other three cases (Rusu, 2006; Kotian et al., 2016; Mao and Li, 2017).

Absent Testicular Artery

Kotian et al. (2016) reported two cases where there was no TA. Thangaraj and Vishali (2017) also reported a case of absence of the TA. Nordmark (1977) reported bilateral agenesis of the TA in one of 32 samples. Variations in the number of TAs are summarized in Table 5.

VARIATIONS BASED ON ORIGIN

From the Abdominal Aorta

The TA usually originates from the lateral aspect of the AA, just below the renal vessels. Anson and McVay (1936) and Cauldwell and Anson (1943) reported that in more than two-thirds of cases the TA originated from the AA at the level of the L2/L3 vertebra. Arteries arising above this level are considered high origin, whereas those arising below it are considered low origin.

Ozan et al. (1995), Asala et al. (2001), Çiçekcibaşi et al. (2002), and Odekunle and Uche-Nwachi (2007) reported a high origin of the TA at the level of the superior mesenteric artery on the right side. Harrison and McGregor (1957), Önderoğlu et al. (1993), Reddy et al. (2011) and Li et al. (2012) reported a high origin of the TA at or above the level of the right RA. Notkovich reported TAs originating above the level of the RV in 9.87% of cases (Tubbs et al., 2016). Cauldwell and Anson (1943) and Xue et al. (2005) reported a high origin of the right TA but they did not mention the exact site. Various authors have reported a high origin of the left TA at or above the level of the left RA. Cauldwell and Anson (1943) and Ozan et al. (1995) also reported a high origin of the left TA just below the superior mesenteric artery. Shinohara et al. (1990) and Mamatha et al. (2015) reported the left TA originating from the thoracic aorta.

Reports have placed the low origin of the TA entirely at the level of the inferior mesenteric artery. Gurses et al. (2009), Bandopadhyay and Saha (2009), Mohandas et al. (2014), Lavy et al. (2015) and Kotian et al. (2016) reported a low origin on the right side. Jyothsna et al. (2012), Nayak et al. (2013) and Kotian et al. (2016) reported a low origin on the left side. Chakravarthi (2014) reported a case of a common trunk that divided into an inferior mesenteric artery, an accessory renal artery, and the left TA. This common trunk originated 2.5 cm above the termination of the AA. Mamatha et al. (2015) reported a unique case of a right TA originating from the right inferior epigastric artery.

Adebisi and Singh (2000) reported five cases in which the TA originated from the AA as a common trunk and later divided into right and left TAs. Table 6 and Figure 2a summarize the variations based on origin from the AA.

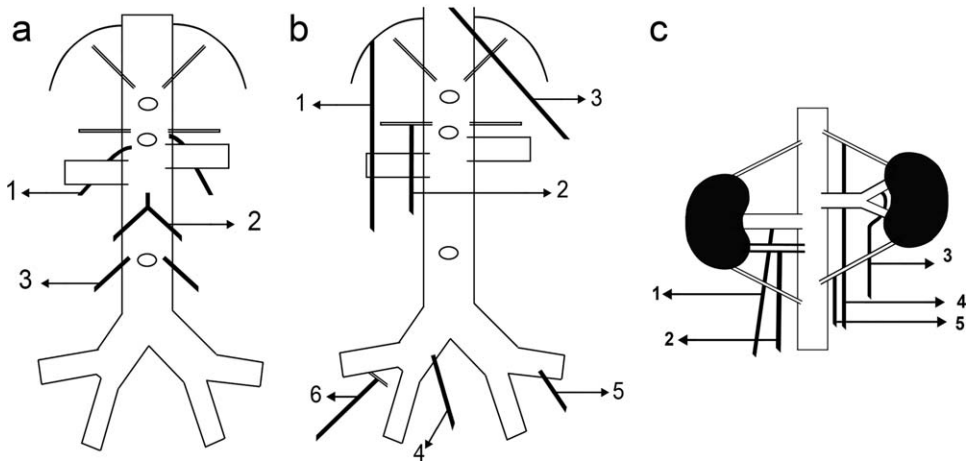

Fig. 2. Variations of origin of the testicular artery (TA). (**a**) From the abdominal aorta (AA): 1, high origin; 2, single TA dividing into right and left branches; 3, low origin. (**b**) From other arteries: 1, from the subcostal artery; 2, from the middle suprarenal artery; 3, from the thoracic aorta; 4, from the common iliac artery; 5, from the external iliac artery; 6, from the inferior epigastric artery. (**c**) From the renal artery (RA) and its associated arteries: 1, from the main RA; 2, from the accessory RA; 3, from the segmental RA; 4, from the superior polar artery; 5, from the inferior polar artery

From the Renal and Associated Arteries

A variant TA can originate from the main RA, the segmental RA, the accessory RA, or an aberrant/polar RA (Fig. 2c). Variations of the RA are most common, and in some studies, TA variations were an incidental finding (Kumar et al., 2010). Reported variations of the TA originating from the RA are summarized in Table 7.

From Other Arteries

Various authors have reported cases of the TA originating from arteries other than the AA and the RA. Çiçekcibaşi et al. (2002) and Wadhwa and Soni (2010) reported the TA originating from the suprarenal artery. Adachi reported the origin of the TA along with the suprarenal artery as a common trunk (Tubbs et al., 2016). Mamatha (2011) reported the TA

TABLE 7. Variations in the Origin of the Testicular Arteries (TAs) Based Upon Their Level from the Abdominal Aorta (AA)

Origin		Right	Left
High origin	Superior mesenteric artery level	Ozan et al. (1995), Asala et al. (2001)	Ozan et al. (1995)
	Renal Artery (RA) level (at or above)	Harrison and McGregor (1957), Önderoğlu et al. (1993), Çiçekcibaşi et al. (2002), Odekunle and Uche-Nwachi (2007), Reddy et al. (2011), Li et al. (2012)	Brohi et al. (2001), Loukas and Stewart (2004), Satheesha (2007), Pai et al. (2008), Mamatha et al. (2010), Natsis et al. (2010), Raikos et al.(2010), Paraskevas et al. (2011), Singh et al. (2011), Li et al. (2012), Rao et al. (2012), Nayak et al. (2013), Tadipi et al. (2015), Kotian et al. (2016)
	Thoracic aorta		Shinohara et al. (1990) , Mamatha et al. (2015)
	Not mentioned	Cauldwell and Anson (1943), Xue et al. (2005)	Cauldwell and Anson (1943)
Low origin	Inferior mesenteric artery level	Bandopadhyay and Saha (2009), Gurses et al. (2009), Mohandas et al. (2014), Lavy et al. (2015), Kotian et al. (2016)	Rao et al. (2012), Chakravarthi (2014), Nayak et al. (2013), Kotian et al. (2016),
	Inferior epigastric artery	Mamatha et al. (2015)	
Miscellaneous	Common trunk from AA	Adebisi and Singh (2000)	

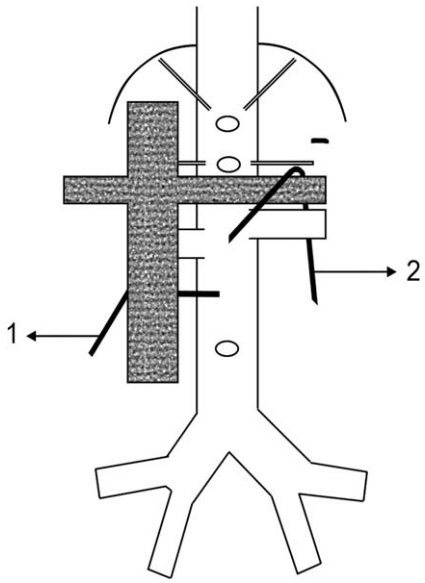

Fig. 3. Variations in the course of the testicular artery (TA): 1, retrocaval course; 2, arching TA.

originating from the right common iliac artery, Thomas et al. (2015) reported it originating from the left external iliac artery, Mamatha et al. (2015) from the right inferior epigastric artery. Mazengenya (2016) reported the right subcostal artery as origin, while Naito et al. (2011a,b) reported an abnormal middle mesenteric artery as origin. Merklin and Michael had reported cases of the TA originating from the celiac trunk and the superior mesenteric artery (Wadhwa and Soni, 2010). Reported variations of the TA arising from other arteries are summarized in Figure 2b.

VARIATIONS BASED ON THE COURSE OF THE ARTERY

The TA arises as a lateral branch of the AA below the level of origin of the RA. On the right side, it passes anterior to the IVC and posterior to the middle colic and ileocolic arteries and the terminal ileum. On the left side, it passes posterior to the inferior mesenteric vein, left colic artery, and descending colon. Further, it descends inferolaterally toward the pelvis along the psoas major muscle under the cover of the parietal peritoneum. It enters the ipsilateral deep inguinal ring and travels to the corresponding testis (Goldstein and Mehta, 2016).

The Arching Testicular Artery

Normally, the TA descends inferolaterally after its origin from the AA. However, sometimes it ascends behind the renal pedicle, arches over and descends in front of the RV (Fig. 3). This variant is described as an arching artery of Luschka (Gupta et al., 2011). Pick and Anson, Notkovich, and Anson and Kurth were among the first authors to report the incidence of an arching TA (Grine and Kramer, 1981; Tubbs et al., 2016). Kamina reported it in 22% of cases (Tubbs et al., 2016). Many authors have reported arching of the TA to be more common on the left side than the right. Nathan et al. (1976), Grine and Kramer (1981), and Adebisi and Singh (2000) reported bilateral arching. Nathan et al. (1976) and Adebisi and Singh (2000) reported the arching of both TAs over the left RV, whereas Grine and Kramer (1981) reported it over the corresponding RVs. Table 8 summarizes reports on arching of the TA by various authors.

The Retrocaval Course of the Right Testicular Artery

Various authors have reported a retrocaval course rather than the normal anterior course of the right TA (Notkovich, 1955; Önderoğlu et al., 1993; Mirapeix et al., 1996; Asala et al., 2001; Özdemir et al., 2004; Bhaskar et al., 2006; Lelli et al., 2007; Wadhwa and Soni, 2010; Reddy et al., 2011; Li, 2015; Nallikuzhy et al., 2017; Mao and Li, 2017; Fig. 3).

ABERRANT BRANCHES FROM THE TESTICULAR ARTERY

Normally, in the abdomen, the TA gives off branches to the perinephric fat and ureter (Goldstein and Mehta, 2016). Various authors have reported unusual branches from the TA to the suprarenal gland, kidney, and diaphragm. The most common branch was the suprarenal artery, particularly the inferior suprarenal artery. Table 10 lists the unusual branches of the TA and the authors who reported them.

PROPOSED CLASSIFICATION OF TESTICULAR ARTERY VARIATIONS

From the observations made from the studies reviewed here, we propose a classification of the TAs based on I. Number, II. Origin, and III. Course of the artery:

I. Number of arteries [N].
N1—Single TA.
N2—Multiple TAs.
N2a—All TAs arising from the AA.
N2b—TAs arising from different arteries.
N3—Absent TA.
II. The origin [O].
O1—Origin of TA from the AA.
O1a—Normal level of origin.
O1b—High origin.
O1c—Low origin.
O1d—A single arterial trunk arising from the AA and dividing into right and left TAs.
O2—Origin of TA from the RA and associated arteries.
O2a—Origin from the main RA.
O2b—Origin from the segmental RA.
O2c—Origin from the accessory RA.
O2d—Origin from the polar RA.
O3—Origin from any other artery.III. Course of the artery [C].

TABLE 8. Variations of the Testicular Arteries (TAs) Based on Its Origin from the Renal Artery (RA) and Associated Arteries

Origin		
RA	Right	Cauldwell and Anson (1943), Nordmark (1977), Bergman et al. (1992), Asala et al. (2001), Petru et al.(2007), Shoja et al. (2007), Pai et al. (2008), Sylvia et al. (2009), Wadhwa and Soni (2010), Panyanetinad (2011), Sharma and Salwan (2011), Mohandas et al. (2014), Paraskevas et al. (2014), Otulakowski and Wozniak (Tubbs et al., 2016), Nallikuzhy et al. (2017)
	Left	Cauldwell and Anson (1943), Adebisi and Singh (2000), Deepthinath et al. (2006), Odekunle and Uche-Nwachi (2007), Petru et al. (2007), Shoja et al. (2007), Jetti et al. (2008), Wadhwa and Soni (2010), Gupta et al. (2011), Kotian et al. (2016)
Segmental branch of RA	Right	Acar et al. (2007), Nayak et al. (2007), Shoja et al. (2007), Pai et al. (2008)
	Left	Petru et al. (2007), Shoja et al. (2007), Tadipi et al. (2015)
Accessory RA	Right	Sekiya et al. (1997), Bordei et al. (2004), Rusu (2006), Tanyeli et al. (2006), Odekunle and Uche-Nwachi (2007), Petru et al. (2007), Xue et al. (2007), Gurses et al. (2009), Gupta et al. (2011), Naito et al. (2011a), Singh et al. (2011), Mamatha et al. (2015), Park et al. (2015), Tadipi et al. (2015), Singla et al. (2016),
	Left	Sekiya et al. (1997), Kocabıyık et al. (2005), Deepthinath et al. (2006), Odekunle and Uche-Nwachi (2007), Petru et al. (2007), Xue et al. (2007), Gurses et al. (2009), Sylvia et al. (2009), Soni and Wadhwa (2010), Gupta et al. (2011), Naito et al. (2011a), Filipovic et al. (2012), Magotra et al. (2013), Jeon et al. (2014), Mamatha et al. (2015), Thangaraj and Vishali (2017)
Superior polar artery	Right	Shoja et al. (2007)
	Left	Rai et al. (2013)
Inferior polar artery	Right	Bergman et al. (1992), Ravery et al. (1993), Çiçekcibaşi et al. (2002), Shoja et al. (2007), Pai et al. (2008), Salve et al. (2010), Panagouli et al. (Tubbs et al., 2016)
	Left	Çiçekcibaşi et al. (2002), Shoja et al. (2007), Pai et al. (2008), Panagouli et al. (Tubbs et al., 2016)

C1—TA originating from the AA.
C1a—Normal course.
C1b—Arching TA.
C1c—Retrocaval course of the TA.
C1d—TA passing through a plexus of renal vessels.
C2—TA originating from other arteries.

Notes:

The right and left sides should be measured separately.

In "O2," the position of the segmental/accessory/polar RA should be noted as superior/inferior to the main RA.

3. In "O3," the artery from which the TA arises should be mentioned in parenthesis.

4. In "C2," a brief course of the TA originating from other vessels should be mentioned.

For multiple TAs, the origin and course of each TA should be noted serially (proceeding from above downwards or from medial to lateral).

Case example:

Right side: double TAs, both arteries originating from the AA, one at a higher level of origin with a normal course and the other at a lower level of origin with a retrocaval course.

Left side: single TA arising from the AA at a normal level and arching over the RA.

Description according to the proposed classification:

Right—N2b, (O1b, C1a) (O1c, C1c); left—N1, O1a, C1b

VARIATIONS IN THE ABDOMINAL SEGMENT OF THE TESTICULAR VEINS

In the abdominal segment, the TV can vary in number and site of drainage. Usually, a single TV enters the abdominal cavity through the deep inguinal ring and drains into the IVC on the right side and into the left RV on the left (Goldstein and Mehta, 2016).

Variations in the Number of Veins

Various authors have reported 2–6 TVs on one side. These veins can present with complete or partial duplication. Partially duplicated veins are classed as either two or more veins joining together to form a single vein before drainage or a single main vein dividing into smaller veins before drainage (Fig. 4a–c). The most common type of multiple TVs is the double/duplicated variety. Asala et al. (2001) described three types of duplication in TVs: Type I: duplication throughout the course; type II: duplicated veins uniting to form a single vein before drainage (left side); type III: bilateral duplication with beaded appearance of the veins. Various authors have reported three to four TVs (Comhaire et al., 1981; Sofikitis et al., 1993; Verma et al., 2005; Favorito et al., 2007; Yang et al., 2008; Anjamrooz et al., 2012; Mazengenya, 2016; Mao and Li, 2017). Sofikitis et al. (1993) also reported one to five TVs at the lumbar level, all of them joining

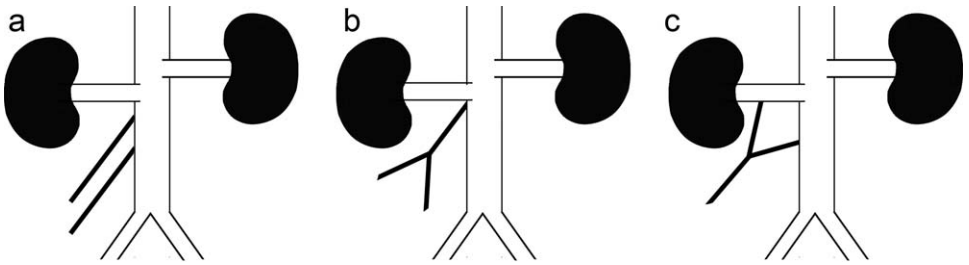

Fig. 4. Multiple testicular veins (TVs). (**a**) Complete duplication. (**b**) Multiple veins joining to form a single TV before drainage. (**c**) Single TV dividing into multiple veins before drainage

before their drainage. Lechter et al. (1991) reported four to six veins in the lower third of the abdomen. Asala et al. (2001), Verma et al. (2005), Fernandes et al. (2012) and Tubbs et al. (2005) reported bilateral duplication of the TVs. In the study by Asala et al. (2001), the duplicated TVs joined to form a single vein before its drainage into the IVC on the right side, whereas Verma et al. (2005) reported that the right-sided duplicated vein divided further and drained as triple veins into the IVC. Lalwani et al. (2017) observed a terminal division of the TV into two veins in six cases and complete duplication of the veins in the rest. Table 9 summarizes the variations in the number of TV.

Variations in the Site of Drainage

Normally, the TV drains into the IVC on the right side and the RV on the left. However, the sites of drainage can vary. Such variations in the TV are more common on the right side. Among the reported variations, most TVs drained into the right RV, but in a few cases they drained into the confluence of the right RV and the IVC, or into the accessory RVs (Fig. 5a–c). Bensussan and Huguet (1984) reported a case of right double TVs draining on either side of the IVC and another case of the right TV draining into the left side of the IVC (Bensussan and Huguet, 1984). Normally, the left TV drains into the left RV. However, in a few cases, it drains into the IVC or accessory RV (Fig 5a). Tubbs et al. (2005) reported a unique case in which both the right and left TVs drained into the corresponding subcostal veins (Fig 5c). Daniel et al. (2016) reported a case in which both the right and left TVs drained into the left RV. Abnormal tributaries from the duodenal and suprarenal veins draining into the TV have been reported. An unusual anastomosis between the TV and the splenic vein was also reported in earlier studies (Tubbs et al., 2016). Common variations of drainage of the TV reported by various authors are included in Table 10.

PROPOSED CLASSIFICATION OF VARIATIONS IN THE TESTICULAR VEINS

I. Number of veins [N]

N1—Single TV.

N2—Multiple TVs.

N2a—Multiple veins throughout the course of the TV.

N2b—Multiple veins joining to form a single TV.

N2c—Single TV dividing into multiple veins before drainage.

II. Site of drainage [D]

D1—Drainage into the IVC on the right side and the RV on the left.

D2—Drainage into the RV on the right side and the IVC on the left.

D3—Drainage into the confluence of the IVC and the RV on both sides.

D4—Drainage into other veins.

TABLE 9. Arching Testicular Artery (TA) as Reported by Various Authors

Side	Right RV	Left RV
Right	Notkovich (1955), Grine and Kramer (1981), Mirapeix et al. (1996), Ozdemir et al. (2004), Kotian et al. (2016),	Adebisi and Singh (2000)
Left		Notkovich (1955), Grine and Kramer (1981), Sekiya et al. (1997), Adebisi and Singh (2000), Naito et al. (2006), Rusu (2006), Acar et al. (2007), Lelli et al. (2007), Nayak et al. (2007), Ranade et al. (2007), Bandopadhyay and Saha (2009), Wadhwa and Soni (2010), Pick & Anson (Gupta et al., 2011), Gupta et al. (2011), Li (2015), Nallikuzhy et al. (2017)
Bilateral arching	Grine and Kramer (1981)	Nathan et al. (1976), Grine and Kramer (1981), Adebisi and Singh (2000)

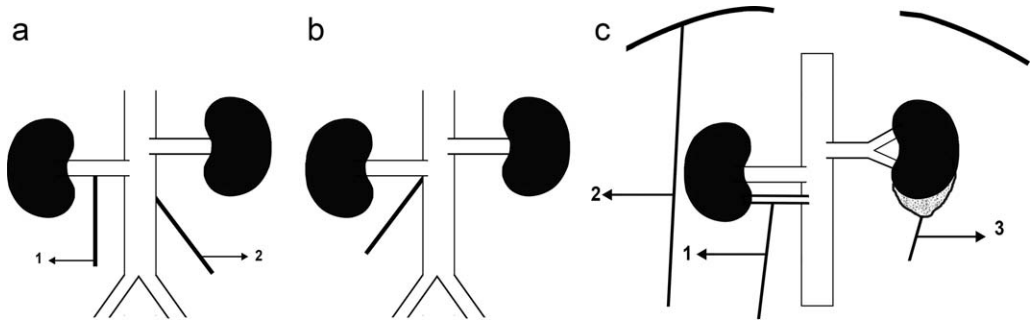

Fig. 5. Variations in site of drainage of testicular veins (TVs). (**a**) 1, right TV into the right renal vein (RV); 2, left TV in to the inferior vena cava (IVC). (**b**) Into the confluence of the IVC and the RV. (**c**) Into other veins: 1, the accessory RVs; 2, the subcostal veins; 3, the perinephric fat pad.

Notes:

1. The right and left sides should be measured separately.
2. In "N2," the total number of TVs should be noted in parenthesis.
3. In "D4," the vein into which the TV is draining should be mentioned.

Case example:

Right side: a single TV draining into the IVC.

Left side: double TVs, duplicated throughout the course, one vein draining into the left RV and the other into the IVC.

Description according to the proposed classification:

Right—N1, D1; left—N2a (2), D1, D2.

EMBRYOLOGY

During development, the lateral mesonephric arteries originate from the dorsal aorta to supply structures on the dorsal body wall. Initially, there are almost 30 arteries on either side. With further development, some of these regress in a craniocaudal direction. However, 9–11 mesonephric arteries persist in the lower thoracic and lumbar regions. These arteries are classified as cranial, middle and caudal groups. The phrenic, suprarenal, renal, accessory renal, gonadal, accessory gonadal arteries, and branches to the lymph nodes and sympathetic ganglia, arise from these lateral mesonephric arteries.

Usually, the TAs arise from the caudal group. However, a TA can arise from the mesonephric arteries in any of these groups or as a branch of a mesonephric artery, accounting for the variations in origin. All the mesonephric arteries disappear except one, which persists in adult life as the main gonadal artery. Failure of the remaining lateral mesonephric arteries to regress explains the presence of multiple TAs in some subjects. The RA also develops from the caudal group of mesonephric arteries. The kidneys, when they ascend, lose their caudal arterial supply and gain a cranial arterial supply. Persistence of the caudal arterial supply along with a high origin or a normal origin of the TA from the AA leads to arching of the TA over the RA or the accessory renal vessels (Felix et al., 1912). The retrocaval course of the TA is closely related to the development of the IVC. The renal

TABLE 10. Aberrant Branches of the Testicular Artery (TA) Supplying Structures Other Than Testes

Artery to		Right	Left
Suprarenal gland	Superior	Önderoğlu et al. (1993)	Shinohara et al. (1990)
	Middle	Ozan et al. (1995), Reddy et al. (2011), Li et al. (2012)	
	Inferior	Harrison and McGregor (1957), Asala et al. (2001), Bhaskar et al. (2006), Nayak et al. (2007), Pai et al. (2008), Panyanetinad (2011), Kotian et al. (2016), Nallikuzhy et al. (2017)	Brohi et al. (2001), Paraskevas et al. (2011), Filipovic et al. (2012), Rao et al. (2012), Kotian et al. (2016)
Kidney		Harrison and McGregor (1957) (accessory renal artery (RA)), Ambos et al. (1980) (renal capsular), Ozan et al. (1995) (superior polar RA), Pai et al. (2008) (renal capsular)	Mamatha et al. (2015) (renal capsular), Kotian et al. (2016) (communicating branches to RA)
Diaphragm—inferior phrenic		Önderoğlu et al. (1993)	Shinohara et al. (1990) (accessory)

TABLE 11. Variations of the Testicular Veins (TVs) Based on the Number

No: of veins	Right Fully duplicated	Right Partially duplicated	Left Fully duplicated	Left Partially duplicated	Bilateral Fully duplicated	Bilateral Partially duplicated
Double	Comhaire et al. (1981), Asala et al. (2001), Xue et al. (2005), Kara et al. (2012), Abraham et al. (2015), Abraham (2016)	vein divided Shafik et al. (1990), Sofikitis et al. (1993), Gupta et al. (2015), Nayak et al. (2013), Lalwani et al. (2017)	Shafik et al. (1990), Asala et al. (2001), Ranade et al. (2007), Pai et al. (2008), Kara et al. (2012), Lavy et al. (2015)	vein divided Sofikitis et al. (1993), Paraskevas et al. (2012), Lalwani et al. (2017)	Asala et al. (2001) (left side), Tubbs et al. (2005) (both sides) Verma et al. (2005) (left side), Fernandes et al. (2012) (both sides)	Asala et al. (2001) (right side, veins joined)
	Bensussan and Huguet (1984), Favorito et al. (2007), Yang et al. (2008), Malar (2016)	veins later joined to form single vein Bensussan and Huguet (1984), Xue et al. (2007), Gupta et al. (2015)	Comhaire et al. (1981), Bensussan and Huguet (1984), Favorito et al. (2007), Xue et al. (2007), Gupta et al. (2015), Malar (2016)	veins later joined to form single vein Bensussan and Huguet (1984), Xue et al. (2005), Natsis et al. (2010), Kara et al. (2012), Mazengenya (2016)		
Triple	Comhaire et al. (1981)	Anjamrooz et al. (2012) (veins joined), Mao and Li (2017) (veins divided)	Comhaire et al. (1981), Sofikitis et al. (1993), Favorito et al. (2007), Yang et al. (2008)			Verma et al. (2005) (right medial vein divided)
Quadruple		Mazengenya (2016) (2/4 veins joined)	Favorito et al. (2007)			
Multiple	Barber et al. (2012), Thangaraj and Vishali (2017)	Bensussan and Huguet (1984), Lechter et al. (1991) (veins join)	Sofikitis et al. (1993), Kumar et al. (2010)	Lechter et al. (1991)		

TABLE 12. Variations of the Testicular Veins (TVs) Based on the Site of Drainage

Side	Draining to	Author
Right	Right Renal Vein (RV)	Crelin (1948), Ahlberg, Rivington (Ahlberg et al., 1966), Comhaire et al. (1981), Shafik et al. (1990), Asala et al., (2001), Sürücü et al. (2002), Favorito et al. (2007), Odekunle and Uche-Nwachi (2007), Jetti et al. (2008), Yang et al. (2008), Sharma and Salwan (2011), Anjamrooz et al. (2012), Kara et al. (2012), Paraskevas et al. (2012), Phalgunan et al. (2012), Abraham et al. (2015), Gardner (2015), Gupta et al. (2015), Abraham (2016), Malar (2016), Singla et al. (2016), Zumstein (Tubbs et al., 2016), Lalwani et al. (2017), Thangaraj and Vishali (2017)
Right	Confluence of Right RV and Inferior Venacava (IVC)	Mirapeix et al. (1996), Comhaire et al. (1981), Itoh et al. (2001), Xue et al. (2005), Favorito et al. (2007), Xue et al. (2007), Nallikuzhy et al. (2017)
Right	Accessory RV	Verma et al. (2005), Nayak (2006), Singh et al. (2011), Park et al. (2015)
Right	Subcostal vein	Tubbs et al. (2005)
Right	Left RV	Daniel et al. (2016)
Left	IVC	Comhaire et al. (1981), Sofikitis et al. (1993), Asala et al. (2001), Malcic-Grubuz et al. (2002), Paraskevas et al. (2012), Lalwani et al. (2017)
Left	Accessory RV	Comhaire et al. (1981), Bensussan and Huguet (1984), Asala et al. (2001), Verma et al. (2005), Kayalvizhi et al. (2011), Uzmansel et al. (2014), Shetty and Nayak (2017)
Left	Subcostal vein	Tubbs et al. (2005)
Left	Perinephric fat	Sofikitis et al. (1993)

segment of the IVC originates from a supracardinal–subcardinal anastomosis. Usually, the main TA passes caudal to this anastomosis. However, if the TA passes cranial to it, it will follow a retrocaval course (Lelli et al., 2007).

Development of the TV is closely related to that of the IVC. Both develop from three venous channels, namely the posterior cardinal, subcardinal, and supracardinal veins. The TV originates from the caudal part of the subcardinal vein and drains into the supracardinal–subcardinal anastomosis. Failure or abnormal involution of the intersubcardinal anastomosis leads to multiple TVs and abnormal drainage (Rudloff et al., 2006; Sharma and Salwan, 2011).

CLINICAL ANATOMY

Variations in the testicular vessels are more common than supposed. Most are found incidentally during surgery. Preoperative awareness of possible variations in the testicular vessels can reduce the risk of complications, especially in renal surgeries. A thorough knowledge of variations of the testicular vessels is essential for radiologists to avoid misinterpretations of angiograms or other investigations.

Any surgery in and around the renal pedicle such as renal transplantation, resection, or embolization of renal tumors, surgeries involving the testes such as resection of a testicular tumor, undescended testis, and so forth, should consider possible variations in the testicular vasculature. An arched TA can compress the renal vessels and this can lead to renal vascular hypertension. Incomplete ligation of multiple testicular vessels can lead to hemorrhage and its complications. Arterial embolization for tumors of the kidney can affect the vascularity of the testis if the TA is a branch of the RA. Incomplete interruption of multiple TVs can lead to failure of varicocelectomy and recurrence.

CONCLUSION

Various authors have reported and classified variations of the testicular vessels. On the basis of various studies reviewed, these variations are more common than supposed. Knowledge of the variations in the testicular vessels is therefore necessary for any surgeon operating in the area concerned. Awareness of possible variations in the vasculature of the testes is necessary to preclude iatrogenic injury to a variant vessel.

We classified testicular vessel variations on the basis of their number, site of origin, course, site of drainage and unusual branches. Our proposed classification facilitates the identification and reporting of variations of the testicular vessels by radiologists and contributes to a better outcome in surgeries related to these vessels.

LIMITATIONS

Full texts were not available for articles, and non-English articles were not included in this review. Variations of the terminal part of the TA supplying the testes and the variations in the origin of the TV were not included. Nor were variations of the TV in respect of the presence or absence of valves, or of the angle of the opening of a vein into the parent vein. This review and classification could be extended by including variations of the TA and TV within the spermatic cord and near the testes. Inclusion of articles from other

databases and languages could highlight more variants and improve the classification further.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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