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Analysis of multiple variations in azygos venous system anatomy with its classification: A cadaveric study

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SUMMARY

The azygos venous system varies greatly in mode of its origin, course, number of vertical channels, number of horizontal anastomoses and nature of termination. Anatomical knowledge of such variations is of immense importance in radiological investigations and surgical intervention of posterior mediastinum pathologies. The present study was undertaken on 30 adult embalmed cadavers aging between 40–65 years, to determine the anatomical variations of the azygos system and to classify accordingly. The vertebral level and diameter of the azygos, hemiazygos, accessory hemiazygos veins at their origin and terminations were also observed. The azygos system was classified into 3 types as per the Anson & McVay system: primitive (type I), transient (type II) and unicolumnar (type III). Type II was further subdivided into 5 subgroups (A to E) according to the number of retroaortic communications. Type I was observed in 1 case (3.33%), type II in 27 (90%) and type III in remaining 2 cases (6.67%). The vertebral level of termination of the azygos, hemiazygos, accessory hemiazygos veins were between T2 and T3, T6 and T10, T6 and T9 respectively. Variations in the formation of azygos system is not an uncommon phenomenon and these variations may easily mislead the radiologists while performing CT/MRI of posterior mediastinum or cardiothoracic surgeons while performing vascular surgeries in this region.

Key words: Azygos vein – Hemiazygos vein – Accessory hemiaygos vein – Anatomical variation

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INTRODUCTION

The azygos system (gr. azygos – 'unpaired' or 'single') which acts as a by-pass between the inferior and superior vena caval systems (Bowsher, 1954) is formed by veins which drain the posterior wall of the thorax and abdomen into the superior vena cava (SVC) (Tatar et al., 2008). It presents a tortuous appearance and usually lies anterior to the bodies of the thoracic vertebrae. The azygos system consists of three interconnected major veins, the azygos (AV), hemiazygos (HV) and accessory hemiazygos veins (AHV) (Snell, 2004; Drake et al., 2005). The AV begins on the posterior abdominal wall usually as a continuation of lumbar azygos vein (which arises from posterior aspect of inferior vena cava) or is formed by the union of right ascending lumbar and right subcostal veins (Shin and Ho, 1999; Standring, 2008). The AV typically leaves the abdomen through the aortic opening or by piercing the right crus of the diaphragm at the level of the 12th thoracic vertebra (T12) (Loukas and Tubbs, 2016). The AV ascends vertically upwards lying in front of the vertebral column up to the level of the 4th thoracic vertebra (T4), where it arches forward superior to the hilum of right lung (which it grooves) to open into the posterior aspect of SVC. The HV is present on the left side. It is formed like the AV in the abdomen from either the continuation of the left lumbar azygos vein that arises from the posterior surface of the left renal vein, or by the union of left ascending lumbar and left subcostal veins. The HV pierces the left crus of the diaphragm and enters the posterior mediastinum. It passes vertically upward lying in front of the vertebral bodies and crosses over to the right side in front of the 8th thoracic

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vertebra (T8) to open into the AV. HV receives posterior intercostal veins of the 9th to 11th intercostal spaces. The AHV begins as a continuation of usually the 5th posterior intercostal vein and descends on the left side of the vertebral column. At the level of 7th thoracic vertebra (T7), it crosses over to the right side behind the descending aorta and the thoracic duct to open into the AV. AHV receives the 5th to 7th left posterior intercostal veins and left bronchial vein (Standring, 2008). The azygos system makes the somatic venous network of the trunk. In pathologic situations it may function as collateral pathway (Dudiak et al., 1989; Mezzogiorno and Passiatore, 1998), and also acts as a metastatic pathway to the lungs (Piciucchi et al., 2014). The anatomy of the azygos system is highly variable in terms of its formation, course, number of tributaries and vertical channels, number of horizontal anastomoses, levels of origin and termination (Ozbek et al., 1999; Kutoglu et al., 2012). It is therefore crucial to classify these variations into types for better understanding.

Starting from the 3rd decade of 19th century until now, many researchers (Seib, 1934; Anson and McVay, 1984; Kutoglu et al., 2012; Dahran and Soames, 2016) have extensively studied the azygos system and provided different types of classification, but this remains a matter of debate and further investigation. It is of immense importance for clinicians to know the normal anatomical organisation, diameter of the constituent vessels and the types of variation before treating any abnormal conditions, as any abnormality of the azygos system can be misdiagnosed as an aneurysm, posterior mediastinal tumor or an enlarged lymph node (Celik et al., 1996). The aim of the current study was therefore to observe the anatomical variations of the azygos system, to make an attempt to put these into the classifications already available in the literature, and to find out the incidence in the population concerned and correlate all of these clinically.

MATERIALS AND METHODS

This study was conducted in Anatomy department (during the years 2015-17) on 30 formalin embalmed adult human cadavers aging between 40-65 years of which 26 were male and 4 female. After the removal of the anterior thoracic wall, heart along with pericardium, lungs, thoracic aorta and esophagus were carefully removed sparing the SVC and IVC. The AV, HV, AHV and posterior intercostal veins were exposed by blunt dissection of the parietal pleura. Subsequently, the diaphragm was depressed to identify the mode of origin of AV and HV. The azygos system was cleaned very carefully by doing fine dissection and made clearly visible. Photographs were taken after painting the veins of the AV system with oil paint.

This study follows the classification of Dahran and Soames (2016), which is an adaptation of Anson and McVay's classification, because it is easier than other classifications. Using the classification of Anson and McVay (1984), the azygos system was classified into one of three types:

Type I or primitive: Two longitudinal azygos lines with no connections in between.

Type II or transitional: There are multiple retroaortic anastomoses between the azygos and hemiazygos venous systems.

Type III or unicolumnar: A single vein located in the midline draining the posterior intercostal veins from both sides.

Type II was further subdivided into 5 groups according to the number of the retroaortic communications (Dahran and Soames classification): group A had 1 communication, group B 2 communications, group C 3 communications, group D 4 communications and group E 5 or more communications. Following classification, schematic drawings of each type and subgroup were also made.

Vertebral levels of origin and termination of AV, HV and AHV were determined by tracing the corresponding rib posteriorly up to the body of the thoracic vertebra. However, as most of thoracic ribs were articulated with 2 vertebral bodies at the same time, the upper one was taken into account. The measurements [in mm] given below were taken with the help of silk thread.

The thread was wrapped around the outer circumference of the vessels (at the level of origin and termination of AV, HV and at termination of AHV) without undue strain, then that particular segment of the thread was cut and spread over glass slide. Using calipers (with least count 0.01mm) between the two ends of the thread, the outer circumference of each section was determined, from which the diameter of the vessel was

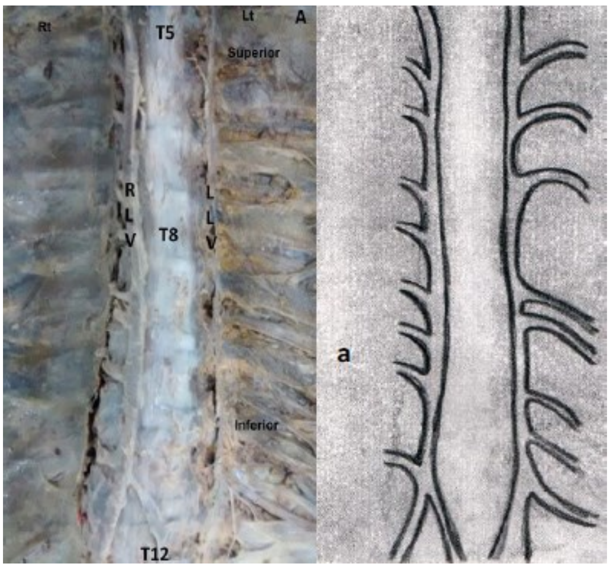

Fig 1. (**A**): Internal view of the posterior wall of the thorax. Type I of the azygos venous system showing right (RLV) and left (LLV) longitudinal venous channels running parallel to each other without any retroaortic communications in between them. (**a**): Schematic drawing of Type I showing 2 completely separate veins lying in the posterior mediastinum. T5, T8, T12: 5th, 8th, 12th thoracic vertebra.

calculated using the formula D (Diameter) = C (Outer Circumference)/π. Most of the veins studied were in collapsed state and didn't get a circular shape in most of cases. Therefore, using such method would be more accurate to determine the diameter of thin walled vein from its outer circumference (perimeter).

Using the method mentioned above, the following diameters were determined:

(A) The diameters of AV and HV at their origins – i.e., immediately after the joining of subcostal and ascending lumbar veins); (B) The diameter of AV just before joining to the SVC; (C) The diameters of HV and AHV just before their joining to the AV.

The vertebral levels of termination of AV, HV and AHV were also determined and compared with previous studies.

RESULTS

Type I was observed in 1 cadaver (3.33%). In this case, right and left longitudinal venous channels were running parallel to each other without any retroaortic communications in between them. The right longitudinal vein drained into the SVC, while the left drained into the left brachiocephalic vein (Fig. 1).

Type II was observed in 27 (90%), being the most commonly observed type in the present study. These cases showed retroaortic connections between AV located on right side and the left sided venous channel (HV and AHV). In our study, the number of these connections varied from one to five. Depending upon the number of connections, these were further subdivided into 5 subgroups (Dahran and Soames classification). Type

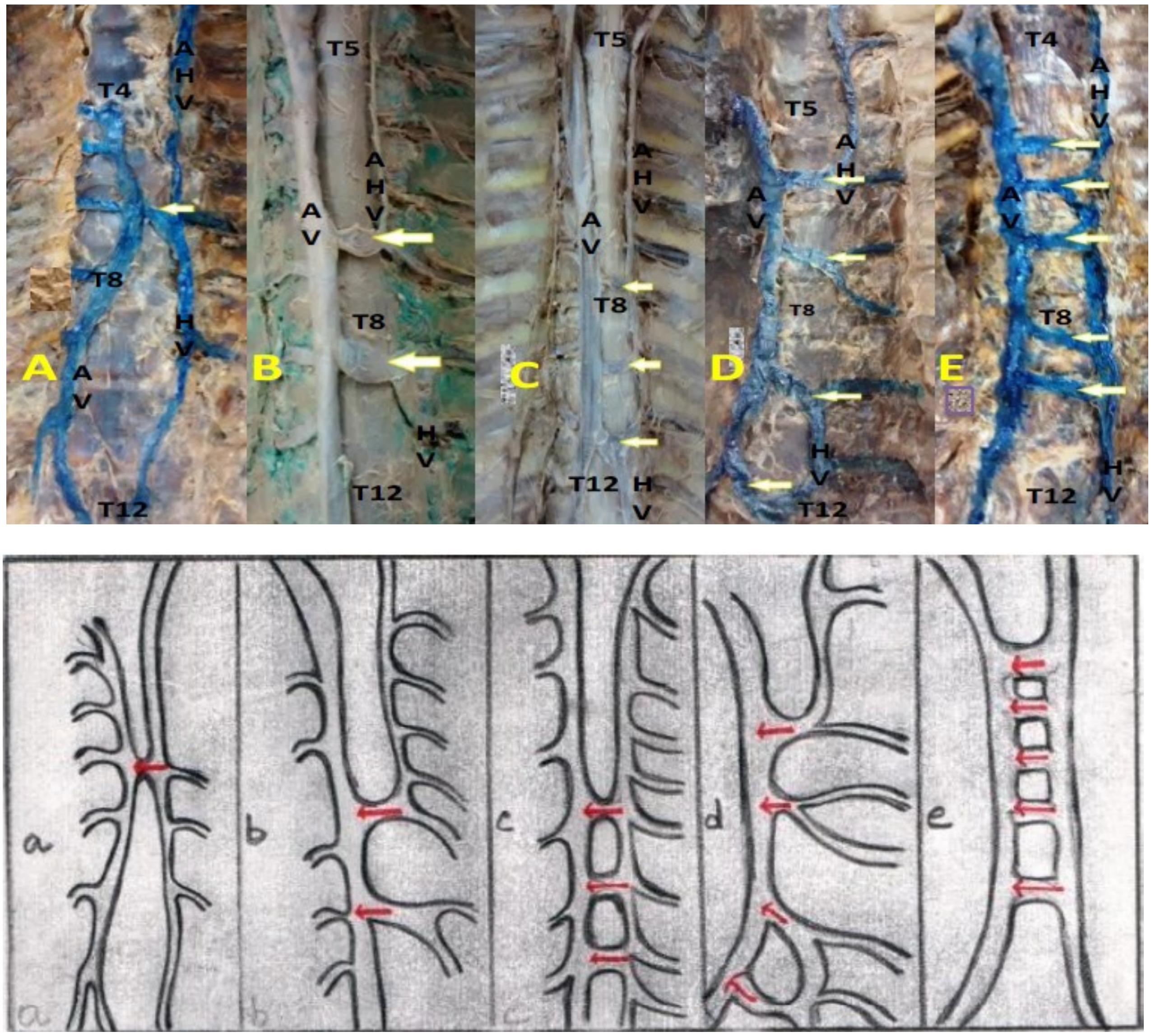

Fig 2. Internal view of the posterior wall of the thorax. Type II and its subtypes A-E showing from 1 to 5 communications (yellow arrows) respectively, between the azygos system. Their schematic drawings can be seen in a-e (red arrows). AV: azygos vein; HV: hemiazygos vein; AHV: accessory hemiazygos vein; T4, T5, T8, T12: 4th , 5th, 8th and 12th thoracic vertebra.

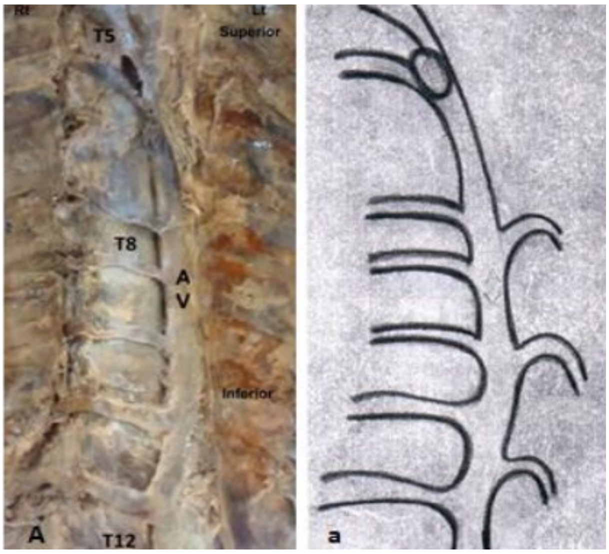

Fig 3. (A): Internal view of the posterior wall of the thorax showing Type III or Unicolumnar azygos vein (AV) located in the midline draining the posterior intercostal veins of both sides directly into it. (a): Schematic drawing of Type III azygos vein: a single column azygos vein on the vertebral column. AV: azygos vein; T5, T8, T12: 5th, 8th, 12th thoracic vertebra.

Table 1. The diameters of the azygos vein, hemiazygos vein and accessory hemiazygos vein at various levels.

Name of Vessel	Level of Origin or Termination	N	Mean (mm)	Range (mm)	S.D (mm)
AV	Origin	30	6.08	5.23-12.50	1.46
AV	Termination into SVC	30	12.21	9.12-17.50	1.58
HV	Origin	28*	3.15	2.15-4.50	0.52
HV	Termination into AV	27**	6.12	4.86-6.50	0.96
AHV	Termination into AV	27**	2.05	1.23-2.65	1.12

AV: azygos vein; HV: hemiazygos vein; AHV: accessory hemiazygos vein; SVC: superior vena cava; SD: standard deviation

* In two cadavers, azygos system belongs to Type III or unicolumnar type in which there was a single azygos vein present in the midline and HV and AHV were absent.

** In two cadavers, HV and AHV were absent and in one which belongs to type I, there was a single left sided vein which terminated into left brachiocephalic vein.

IIA was present in 3 (10%), type IIB in 12 (40%), type IIC in 9 (30%), type IID in 2 (6.67%) and type IIE in 1 cadaver (3.33%) (Fig. 2). Type IIB, consisting of two connections between the right (AV) and left sides (HV and AHV) was the most common subtype.

Type III was observed in 2 cadavers (6.67%), in which the AV and HV united to form a single vein located in the midline (Fig. 3). In 1 case (cadaver no 17), this single channel drained the right and left posterior intercostal veins into the SVC, while in the other 1 (cadaver no 21), the posterior intercostal veins of the right side were draining into this single vein, but on the left side they were passing anteriorly through the costal groove and draining into the internal thoracic vein of left side.

Diameters of different veins of Azygos system: Table 1 demonstrates the mean diameters of different veins of the azygos system. As evident from Table 1, the mean diameters of both AV and HV at the level of termination were almost twice than that at origin.

Table 2. Level of termination of different veins of the azygos venous system

Thoracic vertebral level	Frequency of AV Termination into SVC		Frequency of HV Termination into AV		Frequency of AHV Termination into AV	
	N	%	N	%	N	%
T2	6	20%	-	-	-	-
T2-T3	5	16.67%	-	-	-	-
T3	16	53.33%	-	-	-	-
T3-T4	2	6.67%	-	-	-	-
T4	1	3.33%	-	-	-	-
T6	-	-	-	-	11	36.67%
T7	-	-	10	33.33%	10	33.33%
T8	-	-	12	40%	2	6.67%
T9	-	-	4	13.33%	4	13.33%
T10	-	-	1	3.33%	-	-
Not determined	-	-	3*	10%	3*	10%
Total (N)	30	100%	30	100%	30	100%

AV: azygos vein; HV: hemiazygos vein; AHV: accessory hemiazygos vein; SVC: superior vena cava

* In two cadavers (both belonging to Type III), HV and AHV were absent. In one cadaver (belonging to type I), HV and AHV terminated into left brachiocephalic vein.

Level of termination of different veins of Azygos system: Table 2 demonstrates the vertebral level of termination of different veins of Azygos system.

In 3 cases (1 case of type I and 2 cases of type III), HV and AHV did not terminated into AV. Among these 3, in 1 case (belongs to type I) HV, after its normal origin travelled up along left side of the vertebral column and joined AHV which ultimately drained into left brachiocephalic vein. Remaining 2 cases were of type III or unicolumnar type consisting of a single vein located in the midline, so HV and AHV were absent.

Course of Azygos vein: The AV did not have a constant course in the posterior thoracic wall. In 20 cases (67%), the AV remained on the right side of the vertebral column throughout the whole length, confirming the classical description. In 6 cases (20%), the AV made a longitudinal arch, but the maximum convexity of the arch reached up to the midline of the vertebral column without passing to the left side and returned to its normal terminal course. In 4 cases (13%), the AV ran upwards on the right side of the vertebral column, crossed the mid line and then returned to the right side to terminate into SVC. Thus in these cases, the course of the AV made a wide longitudinal arch with maximum convexity towards the left and crossing midline twice. In the majority of the cadavers, osteophytes on the vertebrae were present; these were found to be well developed, mainly on the right side of the thoracic vertebrae, i.e., in the concavity of the longitudinal arch of the azygos vein.

Our study group included both male and female cadavers of varying age. However, the results could not find any relations between the existence of any particular type of azygos system with age and sex. Moreover, as the sample size of female in this study was 6.5 times lower than that of male (4 versus 26), it was not possible to conclude if there were or not significant differences between both sexes.

DISCUSSION

The veins of the azygos system vary greatly in their mode of origin, course, tributaries, vertical and horizontal anastomoses and termination. These variations are believed to occur during embryonic life. The azygos system arises from the supracardinal veins embryologically. The right supracardinal vein becomes the azygos vein, while the left supracardinal vein becomes the hemiazygos vein (Dudiak et al., 1991). Among the three main constituent veins of the azygos system, AHV is the most variable and may drain into the left brachiocephalic, AV or HV. During the 5th to 7th weeks of embryogenesis, transverse anastomotic channels divert the venous blood from left to the right side, consequent to which veins on the left side shrink in size. Therefore, there is usually a main ‘right-sided’ azygos and at least some representative of the hemiazygos veins seen on the left side. The latter vary, and one or other may be absent or poorly developed. Very rarely, the HV and AHV form a common trunk and, instead of draining separately into the AV, they persist as two independent azygos venous lines (the early embryonic form). Sometimes a single AV may occur in a midline position without hemiazygos tributaries (Kutoglu et al., 2012). Retro-aortic communications between HV, AHV and AV are extremely variable: there may be up to five connections. These connections are often very short, because AV is more commonly lies anterior to the vertebral column and often crosses to the left of the midline for part of its course.

The anatomy of the azygos system has been studied in detail by earlier workers and classified into three main types and their subtypes. Table 3 demonstrates several classification of azygos system used by earlier researchers:

In the present study, the azygos system was primarily classified into 3 types using Anson and McVay’s classification. Table 4 summarises the findings of studies using the same classification. As evident from Table 4, Type II was found to be the most common (90%), which is in consonance with the findings of most of the previous studies. Using Dahran and Soames classification Type II was further subdivided into 5 groups (A-E), depending on the number of retroaortic anastomoses between the right and left azygos lines. Thus compared to Anson and McVay (1984) and Kutoglu et al. (2012), this classification is simpler. Moreover 2 ‘atypical’ cases of Kutoglu et al. (2012), containing

Table 3. Several classification of azygos venous system used by earlier researchers.

		Anson & McVay (1984); Kutoglu et al. (2012)	Dahran & Soames (2016)
Type I or Primitive		Two longitudinal azygos lines with no connections between them	Two longitudinal azygos lines with no connections between them
Type II or Transitional type	Main type	Multiple retro-aortic anastomoses between the azygos and hemiazygos venous systems	Retroaortic communications in the azygos venous system
	Subtypes	- Group 2-5 quantity of the transverse anastomoses increases. There is continuity in the left side. - Groups 6-10, it is seen a vertical bending and the number of the transverse anastomoses decreases gradually	- Group A had 1 communication - Group B 2 communications - Group C 3 communications - Group D 4 communications - Group E 5 or more communications
Type III or Unicolumnar type		A single azygos vein lying at the midline, on the anterior surface of the vertebral column. There is only one subtype (Group 11) of this main type.	A single vein located in the midline draining the posterior intercostal veins from both sides

Table 4. Observations of studies that used Anson McVay's classification .

Author (Year)	Number of specimens	Type I (%)	Type II (%)	Type III (%)
Seib (1934)	200	1-2	-	5
Anson & Mc Vay (1984)	100	1	98	1
Kutoglu et al. (2012)	48	2.1	92	2.1
Dahran & Soames (2016)	30	3.3	86.7	10
Present study (2017)	30	3.3	90	6.7

4 retroaortic connections, are also classified as type IID.

Most of the veins of the azygos system were in collapsed state (did not get a circular shape), and measuring their diameter was difficult. The technique used in this study to determine vessel diameter may be considered as an easy and convenient one for obtaining accurate data. Table 5 compares the findings of the present study with previous similar studies.

On reviewing the results of similar studies by various authors, the diameter of AV, HV and AHV was seen to vary widely. These variations might be due to the sample size under study, methods of measurement, imaging techniques (Tartar et al., 2008 used multidetector CT scan) and confounding factors of the population or ethnic group under study.

Nevertheless, the diameter of AV at termination was found to be maximum in all the cases of Type III, and least in case of Type I. This may be due to the fact that, in the case of type I, only posterior intercostal veins of right side drain into the AV, where, as in case of type III, the unicolumnar AV drains the whole of the posterior body wall into the SVC. The diameter of AV can be hence said to be directly proportional to the amount and direction of blood flowing into it.

In type II, subgroup E had the largest mean diameter, and subgroup A the smallest, which is in consonance with the findings of Dahran and Soames (2016), who also confirmed that the larger the number of communications between the right and left sides of the azygos system, the longer the diameter of the AV at its termination. They also found a positive correlation between the number of communications and the diameter of the AV termination.

An effort has been made to determine the levels of termination of the veins of the azygos system, and results have been compared with previous studies. The current study showed that the most common level of AV termination was at T3 (53.33%), followed by T2 in 20%, and between T2 and T3 in 16.67% of cases. It is similar to Kutoglu et al. (2012) and Dahran and Soames (2016), but not Tatar et al. (2008), who reported that the AV terminates at the level of T5 close to the level of carina in most cases.

Regarding the termination of HV, the present study showed that HV termination was between T7 and T10, the most frequent being T8 (40%) followed by T7 in 33.33%. Kutoglu et al. (2012); and Dahran and Soames (2016) also found it to be at T8 in 27.1% and 33% respectively.

The termination of the AHV was the most variable in the present study. The termination of the AHV was observed to be between T6 and T9, with the most common level being at T6 (36.67%), followed by T7 in 33.33% and T9 in 13.33%. According to Kutoglu et al. (2012) the termination of the AHV varied between T6 and T9 as in our study. However, the most common termination level was at T7. They reported no AHV terminations at the level of T5. According to Dahran and Soames (2016), the AHV terminated between T5 and T9, with the most common level being at T5 (27%) and the second most common at T7 (17%). Hence, we conclude that the AHV is the most variable part of the azygos venous system in terms of its presence, tributaries, communications and level of termination. Left thoracotomy is generally used for thoracic spinal surgeries between T7 and T12 (De Giacomo et al., 2011). As the highly variable termination of the hemiazygos system (T7-T10) overlaps with this area, it would be crucial to preoperatively consider its level of termination in posterior mediastinal and spinal surgeries to avoid injury leading to postoperative catastrophies.

The present work studied the variations in the course of the AV in relation to the midline. It is considered that it may be of assistance in the interpretation of radiographs of the azygos and other veins. We found that, in the majority of cases (67%), the AV remained on the right side, while in

Table 5. Comparison of the diameters of the veins of azygos system observed in present study with similar studies.

Author & year of study	Diameter of AV (mm)		Diameter of HV (mm)		Diameter of AHV (mm)
	At Origin	At termination	At origin	At termination	At termination
Kutoglu et al. (2012)	4.05±1.03	8.56±1.26	3.17±0.70	5.65±1.17	5.47±1.16
Dahran & Soames (2016)	2.14±0.39	6.21±1.36	1.55±0.64	3.23±1.24	1.91±1.02
Tatar et al (2008)		8.11±2.02			
Present study (2017)	6.08±1.46	12.21±1.58	3.15±0.52	6.12±0.96	2.05±1.12

AV: azygos vein; HV: hemiazygos vein; AHV: accessory hemiazygos vein

20% it arched towards midline, but did not cross the same and in 13% crossed the midline to reach left side. According to Nathan (1960), the AV was on the right side of the body in 20%, reaching midline in 27% and in remaining 53% it was crossing to the left side. Tatar et al. (2008) reported AV to remain on right side in 37.90% of cases, located in the midline in 39.80% and in 22.30% of cases reached the left side.

A discussion of previous literature further strengthens our observations that the course of the AV varies widely, although the reason behind such variations remains unclear. Nathan (1960) studied the course of the AV both in adults as well as in still born infants, and showed that in the great majority of the stillborn infants the AV kept to its course on the right side, whereas in old adults it frequently crossed the midline and courses upwards on the left side. Although the number of infants Nathan (1960) dissected was small, still the findings suggested that during life the vein changes course. As no cadavers of older children and young adults were dissected, it was not possible in this work to establish the age at which the deviation most frequently begins.

Our study group included both male and female cadavers, allowing us to examine the differences between the two sexes, but no relationship could be found, which is in agreement with the findings of Tatar et al. (2008) and Kutoglu et al. (2012). However, owing to the difference in the sample size of the two groups in the present study, further studies with equal proportions of males and females are warranted to confirm our observation. Dahran and Soames (2016) have observed a relationship between type IIC and gender in a recent study, with six of the seven cadavers of such type being female, although there was no such relationship with age.

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