APPRASIAL OF THE SURFACE ANATOMY OF THE THORAX IN AN ADOLESCENT POPULATION

Thiasha Nadesan [1], Natalie Keough [1], Farhana E. Suleman [2], Zarina Lockhat [2], Albert N. van Schoor [1,*]

[1] Department of Anatomy, Faculty of Health Sciences, School of Medicine, University of Pretoria, Pretoria, South Africa

[2] Department of Radiology, Faculty of Health Sciences, School of Medicine, University of Pretoria, Pretoria, South Africa

*Corresponding author

Albert van Schoor

Department of Anatomy, University of Pretoria, Private Bag x323, Arcadia, 0007

albert.vanschoor@up.ac.za

ABSTRACT

Surface anatomy is considered a fundamental part of anatomy curricula and clinical practice. Recent studies have reappraised surface anatomy using CT, but the adolescent age group has yet to be appraised. Sixty adolescent thoracoabdominal CT scans (aged 12–18 years) were examined. The surface anatomy of the central veins, cardiac apex, diaphragmatic openings and structures in relation to the sternal angle plane were analyzed. The results showed that the brachiocephalic vein (left & right) formed mostly posterior to the sternoclavicular joint. The superior vena cava formed close to the 2^{nd} costal cartilage, ±16.3mm to the right of the midline. The apex of the heart was located in relation to the 5^{th} intercostal space; ±78.6mm to the left of the midline. The caval hiatus was in relation to T9 and T10; the esophageal hiatus was at T10; while the aortic hiatus was at T11. The sternal angle plane was in relation to the upper half of T5, which was also where the bifurcations of the trachea and pulmonary trunk were observed. The SVC/azygos vein junction and the concavity of the aortic arch were observed to be more than 10mm superior to this plane. The results of this study further highlight the substantial variability of the surface anatomy between age groups. It also emphasizes the notion that surface anatomy is a dynamic variable and cannot be treated as a static observation.

Keywords

anatomy; imaging; medical education; sternal angle; central veins; diaphragm; surface anatomy; adolescent

MeSH Keywords

Adolescents; Anatomic Landmarks/diagnostic imaging; Female; Humans; Male; Thorax/anatomy & histology; Thorax/diagnostic imaging; Tomography, X-Ray Computed;

INTRODUCTION

Surface anatomy is a fundamental part of all anatomy curricula that describes how the position of internal structures relates to the overlying, often bony, surface landmarks. This knowledge is considered essential when performing clinical examinations, interpreting diagnostic images, or performing interventional procedures and surgery (Smith and Darling, 2011; Elliot *et al*., 2012a); however, it is important that evidence-based surface anatomy be taught and that it should also be accurate and up to date to have any clinical value.

Our current knowledge of surface anatomy is derived from anatomical textbooks, many of which were extrapolated from cadaveric studies (Anderson, 1892; Addison, 1898; Lakchayapakorn *et al*., 2008; Mühlberger *et al*., 2008). This approach has many limitations since cadaveric studies do not take into account the changes incurred during the embalming process, or the effects of air in the thoracic cavity, which would have an effect on the position of thoracic structures (Hale *et al*., 2010). Recently, several international studies have been published that have focused on population specific surface anatomy in living subjects by utilizing modern imaging techniques such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound scanning (Emamian *et al.,* 1993; Chukwuemeka *et al.,* 1997; Kim *et al.,* 2003; Soleiman *et al.,* 2005; Glodny *et al*., 2009; Mirjalili *et al*., 2012a; Mirjalili *et al*., 2012b; Mirjalili *et al*., 2012c; Keough *et al*., 2016; Subramanian *et al*., 2016; Tarr *et al*., 2016). These studies reported both similarities and differences between our current anatomical knowledge and the findings of their studies. The main conclusion drawn was that in order for accurate information regarding surface anatomy to be taught, then so too must the accurate possible ranges of variation be incorporated into the education of medical, dental and other health professions students, as well as in the medical sciences, at both undergraduate and postgraduate levels.

Of the studies mentioned above, Subramanian *et al*. (2016), Tarr *et al*. (2016) and Fischer *et al.*, (2017) are the only studies to the authors' knowledge that focus on the surface anatomy of a pediatric population. Their studies show the similarities and differences between an adult and pediatric population, thereby highlighting the need for further comparative studies.

The previously mentioned studies looking at pediatric surface anatomy focused mainly on ages 0 – 12, whilst adult population studies focused only on individuals over 18 years of age (Chukwuemeka *et al*., 1997; Mirjalili *et al*., 2012a, 2012b, 2012c; Pak *et al*., 2015; Shen *et al*., 2015; Uzun *et al*., 2015; Keough *et al*., 2016). Based on the groups (pediatric and adult) the age range between 12 and 18 years (the adolescent age group) has not been evaluated or compared previously. Thus, the purpose of this study is to appraise the surface anatomy of a portion of the South African adolescent population (12 – 18-year old) and compare the findings to other recent local and international studies.

MATERIALS AND METHODS

A sample of 60 (30 male and 30 female) thoracoabdominal CT-scans of patients between the ages of 12 – 18 years of age (mean age: 15.6 years) were obtained from the Department of Radiology at Steve Biko Academic Hospital in Pretoria, South Africa. Only scans taken with the patient in the supine position with the arms fully abducted and at end tidal inspiration were used. Scans that contained an abnormal degree of kyphosis and/or scoliosis, a space occupying lesion or obvious visceromegaly, as diagnosed by the consulting radiologist, were excluded from the study. No volunteers/patients were asked to be a part of this and only scans stored in the database at the Steve Biko Academic Hospital were used.

The measurements were taken as per the guidelines listed below:

Central veins

Brachiocephalic vein (BCV)

The origin of the BCV was identified at the point where the subclavian and the internal jugular veins joined. The position of the left and right BCV was measured on a coronal scan relative to a square created around the limits of each relative sternoclavicular joint.

Superior vena cava (SVC)

The formation of the SVC was identified as the union of the two BCVs on a coronal scan (Figure 1). The position of the union was assessed in relation to the overlying costal cartilages (CC) and/or intercostal spaces (ICS).

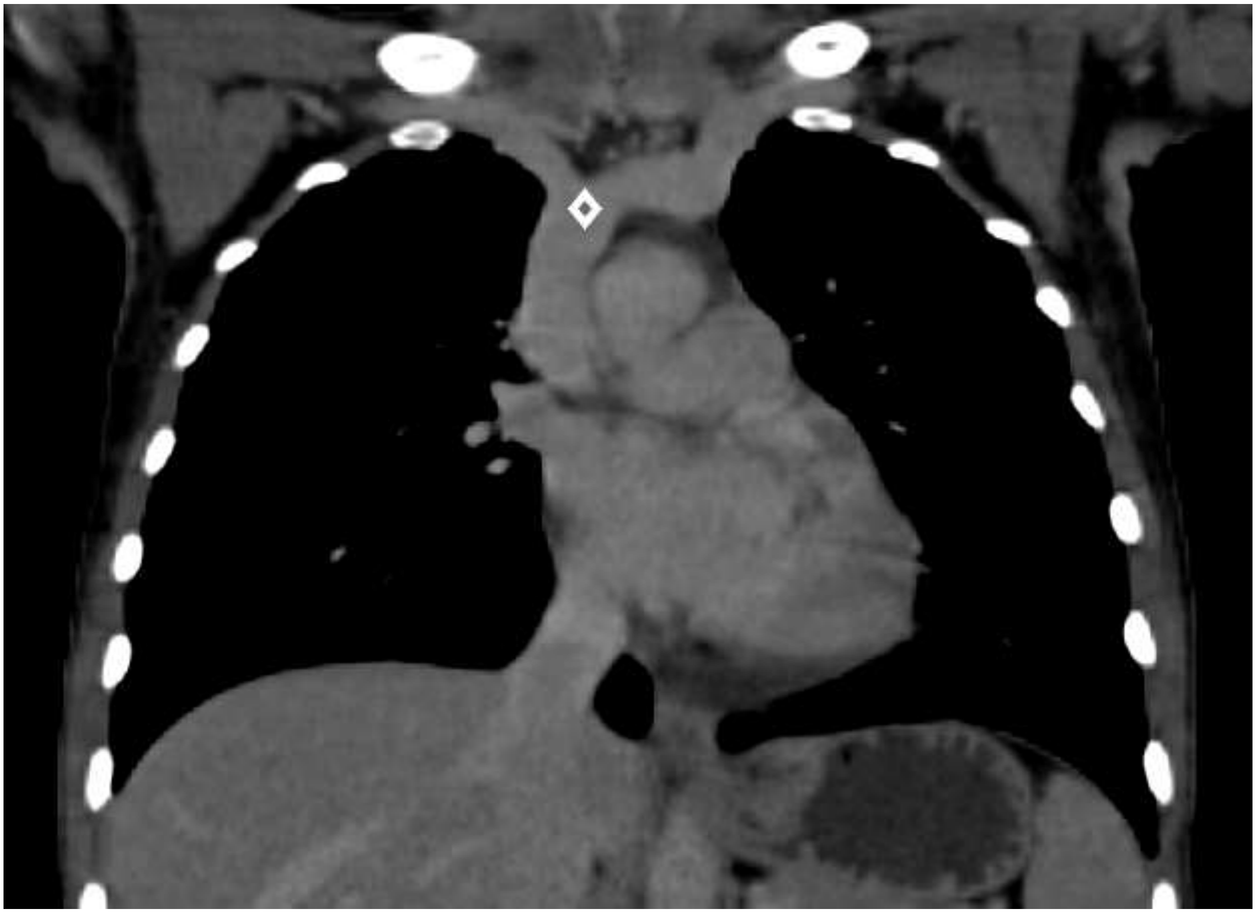

Figure 1. Coronal scan showing SVC formation, with the white diamond shape representing from where the measurement was taken.

Cardiac apex

The cardiac apex was defined as the most inferolateral point of the heart and was identified on a coronal scan. Its position was noted in relation the ribs in the midclavicular line. The distance from the midline was also noted.

Diaphragmatic openings

The vertebral levels of the different openings at which the inferior vena cava (IVC), esophagus and aorta passed through the diaphragm were noted on a coronal and sagittal scan, depending on best visibility.

Sternal angle plane

The plane of the sternal angle, or the angle of Louis, was measured by drawing a horizontal line through the manubriosternal joint on both sagittal and coronal scans and the vertebral level was noted. It was also specified whether the plane intersected the upper or lower half of the vertebrae or the intervertebral disc. The locations of the landmarks commonly associated with the sternal angle plane was also examined and noted. These landmarks included the concavity of the aortic arch, where the azygos vein join the SVC, as well as the bifurcation of the trachea and pulmonary trunk were marked; thereafter, the distance from these landmarks to the line, drawn through the sternal angle plane, was measured. The landmark was considered to be “on the level of the plane” if it was found to be within 10 mm superior or inferior to the sternal angle plane.

Statistical analyses

Data was analyzed using SAS Studio, University Edition statistical software 2018 (SAS Studio, 2018). Descriptive statistics were used to calculate the mean, standard deviation and minimum/maximum values for the metric variables and frequency tables were used to analyze the ordinal and categorical variables. Age and sex were compared against the data sample using the Pearson’s correlation test and 1-way ANOVA tests for the continuous data, and a Wilcoxon’s rank sum test for the ordinal data. The χ^2 test was used for the categorical data. A p-value less than 0.05 was considered statistically significant.

Ethical considerations

This study is covered under the South African National Health Act, 61 of 2003 and received ethical approval from the University of Pretoria’s Research Ethics Committee (146/2018). All scans were retrospectively obtained with the permission of the Head of the Department of Radiology at Steve Biko Academic Hospital, as well as from the hospital CEO.

RESULTS

Measurements and observations were made on scans of 60 adolescent patients (mean age: 15.6 years), equally divided into 30 males (mean age: 15.8 years) and 30 females (mean age: 15.4 years)

Central veins

BCV formation

For the total sample, the position of the BCV was most commonly found to be posterior to the sternoclavicular joint (Figure 2). Sex and age were not considered significant variables (p > 0.05).

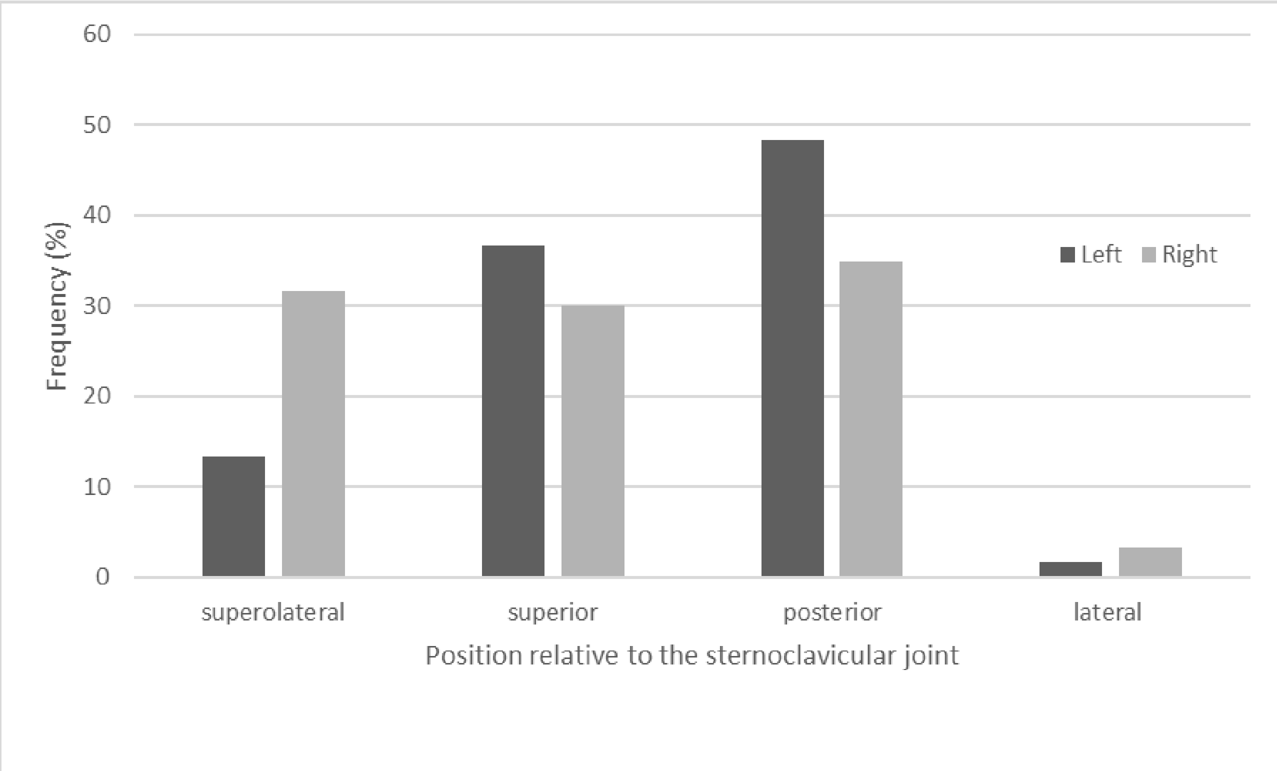

Figure 2: Position of the BCV formation relative to the sternoclavicular joint, left vs. right

SVC formation

The average distance from the midline to the formation of the SVC was approximately 16.3 mm (± 5.8 mm) to the right of the midline, with older males being further from the midline than younger females (p = 0.0412). In relation to the ribs, the SVC was formed most commonly posterior to the 2nd CC (31.7%). The SVC formation showed that age did not affect the position of the formation (p = 0.2868). A significant difference (p = 0.0297) between males and females was found with regard to the position of the SVC formation, with females displaying a more superior SVC formation than males (Table 1).

Table 1: The position of formation of the superior vena cava in relation to the ribs by sex (CC = costal cartilage; ICS = intercostal space)

	n	First CC (%)	First ICS (%)	Second CC (%)	Second ICS (%)	Third CC (%)	Third ICS (%)
Male	30	3.3	30.0	33.3	26.7	-	6.7
Female	30	23.3	26.7	30.0	20.0	-	-
Total	60	13.3	28.3	31.7	23.3	-	3.3

Cardiac apex

The average age for the sample (n = 60) used to evaluate the cardiac apex was 15.6 years old. The cardiac apex was most commonly seen in relation to the 5th ICS (35.0%). Males were seen to have a significantly more superior cardiac apex than females (p = 0.0367). The results of the relation of the ribs to the cardiac apex are noted in Figure 3. The average distance of the cardiac apex was 78.6 mm (± 14.1mm) to the left of the midline (range 47.7 – 111.0 mm). Age did not have a significant effect on the location of the cardiac apex (p = 0.1247).

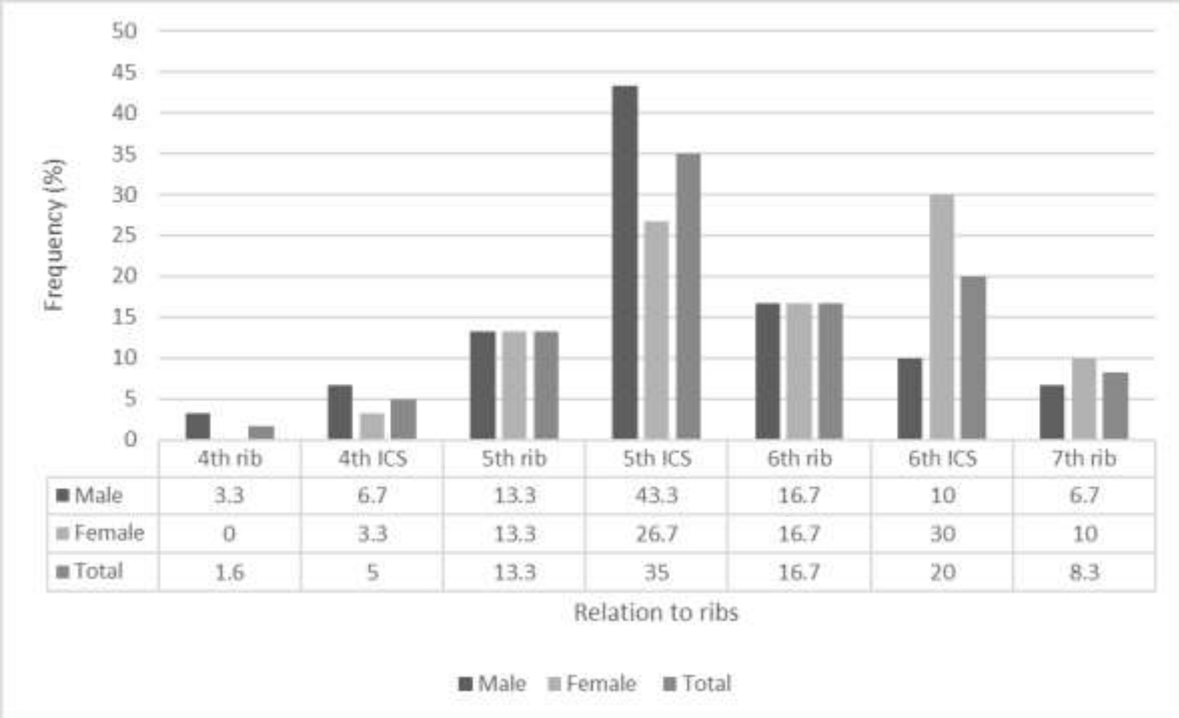

Figure 3: Results of the position of the cardiac apex in relation to the overlying ribs by sex

Diaphragmatic openings

The caval and the esophageal openings of the diaphragm were most commonly at the level of T10 for the sample (36.7% and 50.0% respectively) and the aortic opening was at T11 (46.7%). The vertebral levels for which the IVC, esophagus and the aorta pass through the diaphragm are seen in Table 2. Neither age nor sex showed a significant influence on the vertebral levels of the openings ($p > 0.05$).

Table 2: Results for the vertebral levels at which the caval, esophageal and aortic openings are situated

Vertebral level	Caval (%)	Esophageal (%)	Aortic (%)
T7	-	-	-
T7/T8 disc	-	-	-
T8	6.7	5.0	-
T8/T9 disc	8.3	-	-
T9	31.7	13.3	8.3
T9/T10 disc	11.7	6.7	8.3
T10	**36.7**	**50.0**	20.0
T10/T11 disc	1.7	13.3	8.3
T11	3.3	10.0	**46.7**
T11/T12 disc	-	-	3.3
T12	-	1.7	3.3
T12/L1 disc	-	-	1.7
Total	100	100	100

Sternal angle plane

The vertebral height of the sternal angle was most commonly at the upper half of T5 (20%) (Figure 4). Age and sex did not have a significant influence on the vertebral height of the plane ($p > 0.05$). The bifurcation of the trachea was on average 3.43 mm superior (± 12.67 mm) to the sternal angle plane. The bifurcation was observed outside of the sternal angle plane in 38.3% of cases, superior to the plane in 21.7% of cases (average of 18.87mm), inferior to the plane in 16.7% of cases (average of 18.57mm) and within the 10mm range in 61.7% of cases (average of 3.95mm). Age and sex did not significantly influence this landmark's distance from the plane ($p > 0.05$). The range differed from 33.80 mm inferior to the plane to 27.10 mm superior to the plane.

The bifurcation of the pulmonary trunk was on average 7.01 mm inferior to the plane (± 10.36 mm). In 61.7% of cases, it was noted within the plane with an average of distance of 3.06 mm inferior to the plane. Only 38.3% of cases were considered outside of the plane while 6.67% of all cases were found to be an average distance of 12.35 mm superior to the plane. The average distance of the final 31.7% that was considered inferior to the plane was 18.78 mm. Age and sex did not have an effect on the distance of the pulmonary trunk bifurcation to the sternal angle plane ($p > 0.05$).

The SVC/azygos vein junction was located on average 9.86 mm superior to the sternal angle plane (± 9.95 mm). Age did not influence the location of the junction ($p = 0.9802$), but sex did ($p = 0.0316$). It was seen that the junction is significantly lower in males than in females. In the male sample, the junction was most commonly found within the plane – on average 7.13 mm superior to the pane. In contrast, this junction was found to be 12.74 mm superior to the plane, which would be considered to lie outside of the plane of the sternal angle, in the female sample.

The concavity of the aortic arch was reported on average 16.42 mm (± 21.85 mm) superior to the plane. Neither age nor sex showed a significant influence on the distance of these landmarks to the sternal angle plane ($p > 0.05$). It was found that 83.3% of the total cases lie outside of the sternal angle plane, 68.3% were found to be superior to the plane, with an average distance of 28.24 mm, while 15.0% of cases were inferior to the plane, with an average distance of 21.17 mm. In the 16.7% of cases that were within the sternal angle plane, the average distance on average 0.33 mm inferior to the plane.

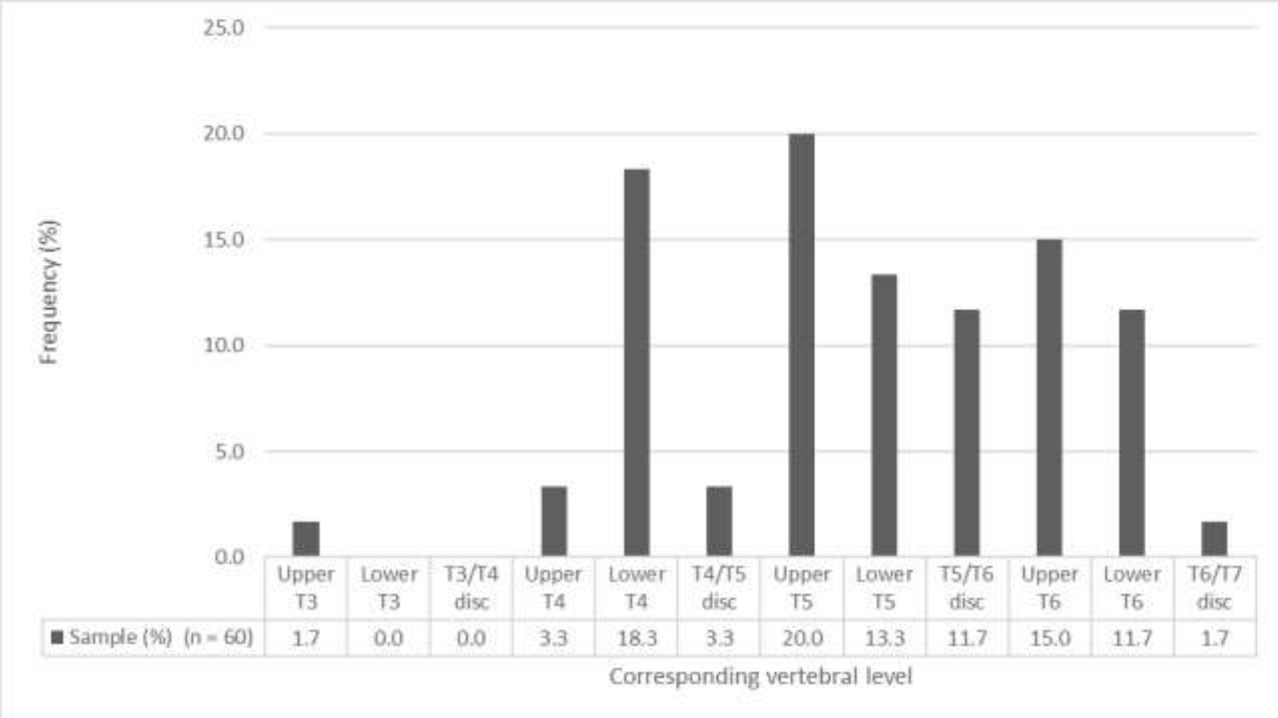

Figure 4: Representation of the relation between the sternal angle plane and vertebral level.

DISCUSSION

Central veins

According to most anatomical reference textbooks, the BCVs most commonly originate posterior to the sternoclavicular joint. However, in this sample it was noted that 51.7% on the left and 65.0% on the right was not found posterior, or within direct relationship to the joint. The formation of the SVC was found between the 1st ICS to the 2nd ICS on the right, approximately 16.31 mm to the right of the midline. Comparison of this studies results with current literature shows the variability between the formation of the BCV and SVC, which in the literature was found mostly posterior to the sternoclavicular joint and most commonly between the 1st CC and the 2nd ICS, respectively (Table 3). Due to the large amount of variation found for the location of the SVC formation, this study would not consider the SVC a reliable landmark for central catheterization on its own, in agreement with the point made by Tarr *et al*. (2016).

Table 3: Age and population comparisons for the results of the central veins

Study	Population	Age (years)	BCV formation		SVC formation
			Left	Right	
Tarr *et al*., 2016	New Zealand	0 – 11	Posterior	Posterior	1^{st} ICS – 2^{nd} CC
	Iranian	0 – 11	Posterior	Posterior	1^{st} ICS – 2^{nd} CC
Current study	South African	12 – 18	Posterior and Superior	Posterior, Superolateral and Superior	1^{st} ICS to 2^{nd} ICS
Mirjalili *et al.,* 2012a	European	>18	Posterior	Posterior	2^{nd} CC
Pak *et al.,* 2015	Iranian	>18	Posterior	Posterior	1^{st} ICS
Shen *et al*., 2015	Chinese	>18	Posterior	Lateral	1^{st} ICS
Keough *et al.,* 2016	South African	>18	Superolateral	Superolateral	1^{st} CC

Cardiac apex

The apex of the heart, defined as the most inferolateral point of the heart, is known to be in relation to the 5^{th} ICS or 6^{th} rib approximately 8.7mm left of the midline (Standring *et al*., 2016). In children younger than 7 years old, it is reported that the cardiac apex lies in relation to the 4^{th} ICS, and at the 5 — 6^{th} ICS in older children (Tasker *et al*., 2013; Park, 2014). This is similar to what was reported in the current study and in recent adult population studies (Mirjalili *et al.,* 2012a; Pak *et al*., 2015; Shen *et al.,* 2015, Keough *et al.,* 2016), as well as in children younger than 4 years old (Fischer *et al.*, 2017) where the cardiac apex was reported at the 5^{th} ICS on the left. Fischer *et al*. (2017) had found that the cardiac apex children older than 4 years old were in relation to the 4^{th} ICS and 5^{th} rib. This is slightly higher than what was found in the current study, or the range reported in pediatric anatomical textbooks (Tasker *et al*., 2013; Park, 2014). The current study had found the apex of the heart to lie approximately 78.6 mm to the left of the midline, which when compared to midline values from other age groups, is expected. The comparison of the distances of the cardiac apex to the midline by age from recent local and international studies is displayed in Table 4.

Table 4: Comparison of distances from the midline by age of the cardiac apex

Study	Age group (years)	Distance from midline (mm)
Fischer *et al*., (2017)	0 – 1	42 (± 10)
	1 - 4	49 (± 11)
	4 - 12	60 (± 10)
Current study	12 - 18	78.6 (± 14.8)
Mirjalili et al. (2012a)	>18	87 (± 10)
Pak et al. (2015)	>18	80 (± 15)
Shen et al. (2015)	>18	83.3 (± 11)
Keough et al. (2016)	>18	81.3 (± 12.8)

Diaphragmatic openings

The caval opening of the diaphragm should be at the T8/T9 intervertebral disc (Mirjalili *et al.,* 2012a; Standring *et al*., 2016). This contrasts what was observed in the current study, which observed the opening most commonly at T10 (36.7%). However, it would be more accurate to say that it passes through the diaphragm between the levels of T9 – T10; which was the case in 80.1% of the sample examined. The caval opening in this study was found at similar levels to that of other recent studies (Table 5). The esophageal opening is described as being positioned at the level of T10 (Standring *et al*., 2016). This concurs with the findings from the current study as 50.0% of the sample demonstrated the opening on the level of T10, putting the opening for the IVC at approximately the same transverse plane. The aortic opening is known to lie in relation to the lower border of T12 (Moore *et al.*, 2015; Standring *et al*., 2016). The current study revealed it to lie in relation to the eleventh thoracic vertebra in most cases (46.7%) and only 3.3% in relation to T12. The esophageal and aortic openings were found slightly more superior than the adult population studies but mostly in line with that of the pediatric population studies (Table 4). A large variation with regard to the surface anatomy of the different openings of the diaphragm is evident (Table 5) and should be expressed in an anatomical curriculum or during clinical training. It is also important to point out that from the results of this study, as well as prior similar studies on a pediatric population, that the domes of the diaphragm are less pronounced, or flatter, when compared to the adult studies. This is an important observation to consider when examining pediatric X-rays for the normal position of the diaphragmatic domes.

Table 5. Comparison of the levels of the openings of the diaphragm

Study	Age (years)	Caval	Esophageal	Aortic
	0–1	T8, T8/T9	T9	T9/T10
Fischer et al. (2017)	1–4	T10	T11	T12
	4–12	T9	T9/T10	T11
Current Study	12–18	T9–T10	T10	T11
Mirjalili et al. (2012a)	>18	T11	T11	T12
Pak et al. (2015)	>18	T10	T11	T12
Shen et al. (2015)	>18	T10	T11	T12
Keough et al. (2016)	>18	T8, T9, T10	T9	T12

Sternal angle plane

The vertebral level of the sternal angle plane was measured by drawing a horizontal line through the manubriosternal joint. This was an unexpected complication as not all of the candidates had fully formed manubriosternal joints due to the age of the samples. Only cases, where the manubriosternal joint was visible as a horizontal line, were used in this study and any errors were compensated for by making sure that the line drawn through the manubriosternal joint was perpendicular to a line drawn vertically through the center of the vertebral bodies. This compensation was used to reduce the margin of error for the level of the manubriosternal joint and also to take into account any possible posture effects. The compensation was also used for any midline measurements for the same effect. In this South African adolescent population, the sternal angle plane corresponded most often with the upper half of the 5th thoracic vertebra. The textbook definition states that the level of the sternal angle plane is between T4 and the upper half of T5 (Mirjalili *et al.*, 2012a; Moore *et al.*, 2015;

Standring *et al*., 2016). Whilst the authors do not necessarily disagree with this definition, it is important to note that 53.3% of the samples in this study were reported to lie inferior to upper half of T5 and that this disparity is a possible range of variation that should be discussed. Compared to other studies that use pediatric and adult populations, this level is slightly lower as these studies had concluded the sternal angle plane to lie mostly at T4 with few of their cases found inferior to this level (Mirjalili *et al.,* 2012a & 2012c; Shen *et al*., 2015; Uzun *et al*., 2015, Keough *et al.*, 2016, Fischer *et al.*, 2017). Chukwuemeka *et al.* (1997) reported the sternal angle to lie at the lower half of the 5th thoracic vertebra, similar to the current study, with a slightly different method.

The landmarks that are commonly associated with the sternal angle plane are the bifurcation of the trachea and the pulmonary trunk, the concavity of the aortic arch and the point where the azygos vein joins with the SVC. For methodical purposes, a 10 mm margin of error was used as the upper margin for whether a measurement could be considered associated with the plane. Therefore, if the distance from the landmark was larger than 10 mm then it was not considered to be associated with the plane. In this South African adolescent sample, it was noted that the bifurcation of the trachea and pulmonary trunk and the SVC/azygos vein junction were associated with the sternal angle plane. The concavity of the aortic arch was seen to lie outside of the plane – more accurately, found superior to this plane in a large majority of the sample – and therefore would not be considered associated with the sternal angle plane. When contrasted with adult population studies (Chukwuemeka *et al*., 1997; Mirjalili *et al.,* 2012a & 2012c; Shen *et al*., 2015; Uzun *et al*., 2015; Keough *et al.*, 2016), the South African adolescent population does not show similar results. The above studies had reported most of their landmarks to lie within or outside and inferior to the sternal angle plane whilst this study had reported most either within or outside and superior to the plane. The study by Keough *et al.* (2016) saw the concavity of the aortic arch to lie superior to the sternal angle plane, which is similar to what was observed in the current study. A possible explanation for the similarity is that Keough *et al. (*2016) and the current had both used a South African population. The study done by Fischer *et al.*, (2017) on a pediatric sample had only found the SVC-azygos vein junction to lie within the sternal angle plane and the other landmarks to lie inferior to the plane, which is similar to what was found in the adult population studies. This study would consider the sternal angle to be a good measure for the locations of the bifurcation of the trachea and pulmonary trunk, based on the adolescent population sample, but this conclusion is contrasting to that of other populations and so this study would rather advocate for more research be done using more populations and age groups in order to provide a definitive remark on which landmarks are associated with the sternal angle plane.

Limitations and considerations

One of the limitations to the study includes the fact that it is known that the vertebral projections of some major thoracic landmarks are affected by respiration and posture (Macklin, 1925; Harris, 1959; Stern, 2015). As with the study conducted by Mirjalili *et al*. (2012a), these limitations were addressed by including only adolescents, all in a supine position using a standard respiratory protocol. This was in an attempt to standardize as many variables as possible.

Another limitation was the lack of information regarding the height, weight and ethnicity of the sample that was examined. This means that a complete analysis of anatomical variation could not be conducted as the effects of height and weight have not been adequately addressed, to the authors' knowledge, for an adolescent or pediatric population. The effect of height and weight on the surface anatomical levels should be minimal, according to the study by Mirjalili *et al*. (2012c) that did look at the effect of BMI on adults.

CONCLUSION

The ability to relate the position of the internal organs to the overlying structures is something expected to be ingrained in all clinical and medical practitioners and so it forms an important aspect of the anatomy curriculum. In general, accuracy in anatomical knowledge has been known to prepare future generations of practitioners for their clinical experiences. Thus, it is important that the knowledge being taught is up to date, accurate and evidence-based in order for it to have any clinical relevance. This study advocates for similar studies to be conducted with different population groups over different ages, using modern and available technology, in order for the possible similarities and differences be highlighted and the correct anatomy as well as the expected ranges of variation be conveyed to students.

Conflict of Interest

The authors have no conflict of interest to report

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