The thoracic surface anatomy of adult black South Africans: a reappraisal from CT scans

Original Communication

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ABSTRACT

Introduction: Surface landmarks or planes taught in anatomy curricula derive from standard anatomical textbooks. Although many surface landmarks are valid, clear age, sex and population differences exist. We reappraise the thoracic surface anatomy of black South Africans.

Materials and methods: We analyzed 76 (female = 42; male = 34) thoracoabdominal CT-scans. Patients were placed in a supine position with arms abducted. We analyzed the surface anatomy of the sternal angle, tracheal and pulmonary trunk bifurcation, azygos vein termination, central veins, heart apex, diaphragm, xiphisternal joint and subcostal plane using standardized definitions.

Results: Surface anatomy landmarks were mostly within the normal variation limits described in previous studies. Variation was observed where the esophagus (T9) and inferior vena cava (IVC) (T8/T9/T10) passed through the diaphragm. The bifurcations of the trachea and pulmonary trunk were inferior to the sternal angle. The subcostal plane level was positioned at L1/L2. The origin of inferior mesenteric artery was mostly inferior to the subcostal plane. Sex differences were noted for the plane of the xiphisternal joint ($p=0.0082$), with males (36%) intersecting at T10 and females (36%) intersecting at T9.

Conclusions: We provide further evidence for population variations in surface anatomy. The clinical relevance of surface anatomical landmarks depends on descriptions of normal variation. Accurate descriptions of population, sex, age and body type differences are essential.

Keywords: Sternal angle; subcostal plane; central veins; diaphragm; apex of heart; xiphisternal joint

INTRODUCTION

The position of organs and structures in relation to visible or palpable surface anatomical landmarks is a core aspect of anatomical teaching and useful in clinical practice. Understanding surface anatomy is essential when examining patients, performing clinical procedures and interpreting diagnostic images (Elliott et al., 2010; Smith and Darling, 2011; Mirjalili et al., 2012a). General surface anatomical landmarks are routinely taught from standard anatomical textbooks, which seldom incorporate sex, age, body mass and population variation (Hale et al., 2010). Anatomical descriptions included in widely used standard texts are mostly derived from historical cadaveric studies (Anderson, 1892; Addison, 1898). Recently, surface anatomical landmarks have been accurately described from living subjects using modern imaging techniques such as X-ray computed tomography (CT) (Chukwuemeka et al., 1997; Glodny et al., 2009; Mirjalili et al., 2012a, b, c), magnetic resonance imaging (MRI) (Kim et al., 2003; Soleiman et al., 2005), and ultrasound scanning (Emamian et al., 1993). In their reappraisals of thoracic and abdominal surface anatomy, Mirjalili et al. (2012a, b, c) reported clear differences between their measurements of various features and those described in anatomical texts. These authors also encouraged that future studies measure possible population variation in human surface anatomy. We add to the current body of knowledge by reappraising the thoracic surface anatomy of supine adults of black ancestry in South Africa. We compare our measurements to current descriptions of surface anatomical landmarks obtained from other population groups.

MATERIALS AND METHODS

We accessed a database of thoracoabdominal CT scans located in the Department of Radiology, Steve Biko Academic Hospital, South Africa. All patients were of African ancestry, which can be defined as individuals that are considered native inhabitants to Africa, particularly black individuals within South African borders. All scans were taken using with a Siemens Medical Somatom Sensation Cardiac 64 (64 slice) CT with a 5 mm slice thickness. Scans of patients in the supine position, taken at end tidal inspiration and with the arms abducted, were included in the study. Scans of patients with an abnormal degree of kyphosis and/or scoliosis, as diagnosed by the consulting radiologist, those with a distorting space-occupying lesion (mass or fluid collection), and those with obvious visceromegaly (enlarged organ/s), were excluded. Thoracic CT scans of 76 patients (42 females and 34 males) were analyzed. The mean age of the subjects was 51.6 years, ranging from 23 to 84 years old. The surface anatomy of the (A) sternal angle, (B) central veins, (C) cardiac apex, (D) diaphragm, (E) xiphisternal joint and (F) the subcostal plane was analyzed using the following definitions:

A) Sternal angle:

The sternal angle (angle of Louis) was defined on sagittal scans as the vertebral level where a horizontal line (sternal plane) drawn through the manubriosternal joint intersected the anterior border of the vertebral column. We recorded the vertebral number and the vertebral level of the intersection. The vertebral level was determined by counting from the fifth lumbar vertebra up, where the fifth lumber vertebra was identified by the position of the lumbosacral angle/junction. We recorded whether the sternal plane intersected the upper or lower half of the body of the vertebra or the intervertebral disc. A unique, identifying number was given to each location.

Vertebral level and the vertical distance from the sternal plane was recorded for the following four structures: (A1) the bifurcation of the trachea defined by the carina; (A2) the level of the azygos vein/superior vena cava (SVC) junction defined by the center of the azygos vein at this junction; and (A3) the bifurcation of the pulmonary trunk represented by a point midway between the midpoint of the left and right pulmonary arteries at their origin. A positive (+) measurement indicated that the structure (A1-A3) was found superior to the plane of the sternal angle, while a negative number (-) indicated that the structure is found inferior to the plane.

B) Central veins:

The origin of the brachiocephalic vein (BCV) was defined as the junction of the subclavian and internal jugular veins and was identified on coronal scans. Upon identifying the origin of the BCV, its position relative to the ipsilateral sternoclavicular joint being either posterior, superior, inferior medial or lateral to the joint, was recorded. The union of the BCVs in the coronal plane defined the formation of the SVC. The SVC/ right atrial (RA) junction was defined as the site where the SVC and RA merged in the sagittal and axial planes. The cranio-caudal level of the SVC surface anatomy was recorded with reference to the costal cartilages (CCs) and anterior intercostal spaces (ICSs).

C) Cardiac apex:

The cardiac apex was defined as the most lateral point of the left border of the heart and was recorded with reference to the CCs, anterior ICSs and the anterior ends of the ribs. The maximum linear distance of the apex from the midline of the body was measured.

D) Diaphragm:

The vertebral levels at which the inferior vena cava (IVC), esophagus, and aorta passed through or behind the diaphragm were identified on both coronal and sagittal scans. The vertebral number, or intervertebral disc, related to the above-mentioned three structures was noted.

E) Xiphisternal joint:

The vertebral level of the xiphisternal joint and whether it intersects the upper half of the body of the vertebrae, lower half, or the intervertebral disc was observed and noted on sagittal CT scans.

F) Subcostal plane

The vertebral level of the subcostal plane, defined by the lower limit of the costal margin, was recorded on coronal CT scans. We noted if the inferior mesenteric artery (IMA) originated from the abdominal aorta within, or outside, 10 mm of this plane.

Statistical analysis

All data were captured in a Microsoft Excel Worksheet and analyzed using Statistix Ver.8. Descriptive statistics included the mean, standard deviation, minimum and maximum of the continuous, numerical data, while the median was determined for categorical data.

Comparisons between groups/measurements (i.e. left *vs.* right, male *vs.* female) were made using a paired-sample and independent-sample t test respectively, $p < 0.05$ indicated a statistically significant difference. The association between collected measurements and age were tested using a Pearson's correlation test. There was a high (strong) correlation between age and measurement if r-value was between 0.75 and 1.0, moderate correlation if r-value was between 0.5 and 0.74 and a poor correlation if r-value <0.5.

Ethical considerations

No volunteers / patients were asked to undergo any form of imaging as part of this study. Only CT scans stored in the database of the Department of Radiology were accessed and analyzed with assistance of, and approval from the Head of the Department and the hospital CEO. This study also received approval from the institutional ethical committee.

Limitations and other considerations of the study

Vertebral projections of major thoracic landmarks may be affected by respiration and posture (Macklin, 1925; Harris, 1959). We standardized as many variables as possible by including only adults in a supine position using a standard respiratory protocol, following Mirjalili et al. (2012a). We were limited by a lack of information regarding the height and weight of the sample. Height and weight should have a negligible effect on surface anatomical levels, but no studies have adequately addressed this.

We focused on CT scans of adult black South Africans for comparative purposes. We compare our results to the *in vivo* surface anatomical landmarks of adults of Chinese (Shen et al., 2016), European (Mirjalili et al., 2012a, c), Iranian (Pak et al., 2016) and Turkish (Uzun et al., 2016) ancestry.

RESULTS

Sternal angle

The vertebral level of the sternal plane ranged between the upper level of T3 and the lower level of T6 (Table 1). The median level of the sternal plane in the total sample passed through the T4/T5 intervertebral disc, but with the highest frequency (23%) through the lower half of T4. Vertebral level of the sternal plane did not differ significantly between the sexes (p=0.492). Vertebral level passed through the upper half of T4 in 21% (n=7) of males and through the lower half of T4 in 26% (n=11) of females. The vertebral level of the sternal plane was not correlated to age (r=-0.3879).

The distance from the sternal plane to the azygos/SVC junction, tracheal bifurcation and pulmonary trunk bifurcation are presented in Table 1. Two structures namely the tracheal bifurcation (p=0.0092) and the pulmonary trunk bifurcation (p=0.0001) were significantly closer to the sternal plane in females.

Table 1

The termination of the azygos vein into the SVC was positioned within 10 mm of the sternal plane in 55%, superior in 11% and inferior in 34% of all scans.

Relative to the sternal plane, the bifurcation of the trachea was superior in seven percent (n=5), within 10 mm in 33% and inferior in 60% of all scans. The tracheal bifurcation was significantly higher (mean = 12.3 mm) in females than in males (p=0.0092).

Relative to the sternal plane, the bifurcation of the pulmonary trunk was superior in 3% (n=2), within 10 mm in 21%, and inferior in 76% of all scans. The pulmonary trunk bifurcation was on average 15.1 mm higher in females than males (p=0.0001).

The positions of the azygos vein/SVC junction and the bifurcation of the trachea and pulmonary trunks negatively correlated with age. There were moderate correlations between age and the position of the azygos vein/SVC junction (r=-0.5641), the bifurcations of the pulmonary trunk (r=-0.5518) and trachea (r=-0.6155).

Central veins

The BCV originated directly posterior to the ipsilateral sternoclavicular joint (SCJ) in only 35% of the scans on the left and 25% on the right. The origin of the BCV was however positioned superolateral to the ipsilateral SCJ in 41% of scans on the left and 37% on the right (Table 2).

Table 2

There was no significant difference between males and females for the junction of the left (p=0.89) and right (p=0.45) BCVs.

Table 3

The SVC originated posterior to the 1^{st} right CC in 78% of all scans, 80% of females and 78% males. The SVC/RA junction was most commonly situated posterior to the right, 3rd CC in 45% of all scans, 37% of females and 59% of males (Table 3). There was no significant sex difference in the SVC origin (p=1.0000) or the SVC/RA junction (p=0.6247).

There was a poor/low correlation between age and the origin of the SVC (r=0.3144) and SVC/RA junction (r=0.4813). Age was poorly correlated with the position of the left (r=-0.0085) and right (r=0.2044) BCVs.

Cardiac apex

The cardiac apex was situated in the left, 5th ICS in 41% of scans and level with the left 5th rib CC in 22% of scans. The cardiac apex was positioned on average 81.3 ± 12.8 mm to the left of the midline (range 40.2 – 114 mm) (Table 4).

Table 4

The distance of the cardiac apex from the midline did not differ between sexes (p = 0.5911). Age was not correlated to the position of the cardiac apex (r=0.35) or to the distance from the midline (r=0.20).

Diaphragm

The vertebral level at which the IVC, esophagus, and aorta passed through/behind the diaphragm are summarized in Table 5.

Table 5

All three structures traversed the diaphragm at a higher vertebral level in females (IVC: p=0.0000; esophagus: p=0.0000; aorta: p=0.0004). Age correlated poorly with the level of the IVC (r=0.2256) and the esophagus (r=0.3623). There was no correlation between age and the level of the aorta (r=0.0115).

Xiphisternal Joint

The plane through the xiphisternal joint passed through the T8/9 intervertebral disc in 20%, the upper half of T9 in 17% and the lower half of T8 in 16% of scans. The vertebral level of the xiphisternal plane was significantly higher females (p=0.0082). The xiphisternal plane intersected with T9 (upper and lower halves of the vertebra) in 36% of females and T10 in 36% of males. Age and the xiphisternal plane were not correlated (r=-0.0880).

Subcostal plane

The subcostal plane was at the level of L1/L2 in 24% of scans. The median vertebral level of the subcostal plane corresponded with the L1/L2 intervertebral disc and ranged from T12/L1 to the L2/L3 intervertebral disc. The subcostal plane was significantly more superior in the female sample (p=0.0010). In males, the subcostal plane was at the L1/L2 intervertebral disc level (27%) and lower half of L2 (27%). In females, the subcostal plane was level with the upper half of L1 in 26% of scans. Age and the level of the subcostal plane were not correlated (r=-0.1133). The IMA originated inferior to the subcostal plane in 84% of scans and within 10 mm of the subcostal plane in 16% of scans.

DISCUSSION

Recent studies have reappraised adult thoracic surface anatomy *in vivo* using modern CT imaging. These studies provide increasing evidence for a range of human variations, which could influence the clinical use of important surface markings. These studies compare the surface anatomical landmarks and planes between different groups, including Chinese (Shen et al., 2016), European (Mirjalili et al., 2012a; Mirjalili et al., 2012c), Iranian (Pak et al., 2016) and Turkish (Uzun et al., 2016) populations. Population variation in surface anatomy has not been described in detail (Uzun et al., 2016). The thoracic surface anatomy of black South Africans was largely congruent with anatomical texts and other population groups. We recorded sex differences not observed in other studies.

Sternal angle

According to anatomy textbooks, the sternal plane intersects with the T4/T5 intervertebral disc posteriorly. Other structures that occur at the T4/T5 level are the level of the azygos vein/SVC junction and where the trachea and the pulmonary trunk bifurcates (Ellis and Mahadevan, 2010; Moore et al., 2010; Standring, 2015). The sternal plane of black adult South Africans mostly intersected the body of T4 or the T4/T5 intervertebral disc, confirming the descriptions reported in popular anatomical textbooks and measurements recorded for Chinese (Shen et al., 2016), European (Mirjalili et al., 2012a, c) and Turkish (Uzun et al., 2016) populations. In black South Africans, the level of azygos vein / SVC junction was mostly found within 10 mm of the sternal plane. The tracheal and pulmonary trunk bifurcations were inferior to the sternal plane (this study). In Chinese (Shen et al., 2016) and Turkish (Uzun et al., 2016) populations the level of the azygos vein / SVC junction and the tracheal and pulmonary trunk bifurcations were inferior. In European populations (Mirjalili et al., 2012a, c), all three structures were inferior to the sternal plane (Table 6).

Table 6

Central veins

In contrast to European (Mirjalili et al., 2012a) and Iranian (Pak et al., 2016) populations, the left and right BCVs of black South Africans were mostly located superolateral to the ipsilateral sternoclavicular joint. Despite no significant sex differences, the right BVC of males was mostly formed directly posterior to the sternoclavicular joint (this study). Sex differences were not present in the Iranian population (Pak et al., 2016). In the Chinese population, the right BCV formed lateral to the joint in 54% of cases, but only formed superolateral in 9% of cases. The position of the sternoclavicular joint may be distorted by the fully abducted posture of the arms, giving rise to lateral position of BCVs observed in this study and in the Chinese population (Shen et al., 2016).

Similar to accepted anatomical texts (Sinnatamby, 2011; Standring, 2015), in black South Africans, the SVC forms to the right of the 1st CC and the SVC/RA junction is to the right of the 3rd CC (this study). These landmarks were at the right 1st and 4th ICSs in a Chinese population (Shen et al., 2016), behind the right 2nd CC and right 4th CC in a European population (Mirjalili et al., 2012a) and finally behind the right 1st ICS and 3rd ICS in an Iranian population (Pak et al., 2016). There were no sex-related differences reported in the Chinese (Shen et al., 2016), Iranian (Pak et al.,

2016) or black South African (this study) populations. In contrast, the SVC/RA junction was significantly higher in females and younger adults from European populations (Mirjalili et al., 2012a).

Cardiac apex

The cardiac apex is located in the left 5^{th} ICS along the midclavicular line (Moore et al., 2010; Standring, 2015). Alternatively, the cardiac apex can be located by measuring 90mm from the midline in the 5^{th} ICS (Naylor et al., 1987). Reappraisals from *in vivo* studies support both these descriptions but also report variations. In Iranian (Pak et al., 2016), European (Mirjalili et al., 2012a), Chinese (Shen et al., 2016) and black South African (this study) populations, the cardiac apex was primarily located at the 5th ICS. The distance from the midline varies between populations. In a European population, the cardiac apex was 87mm ± 10mm to the left of the midline (Mirjalili et al., 2012a) and 83 mm to the left of the midline in a Chinese population (Shen et al., 2016). In the South African sample, the cardiac apex was 81.3 mm ± 12.8 mm to the left of the midline.

Diaphragm

The IVC, esophagus and aorta pass through the diaphragm at vertebral levels T8, T10 and T12, respectively (Moore et al., 2010; Sinnatamby, 2011; Standring, 2015). Table 7 presents a summary of the frequencies through which these three structures passes through the diaphragm on a specific level. The results summarized in the table are a comparison of the black South African (current study), Chinese (Shen et al., 2016) and European (Mirjalili et al., 2012a) populations.

Table 7

The vertebral level where the aorta passes through the diaphragm is the most consistent and similar across all three studies (Table 7). The vertebral level where the IVC and esophagus pass through the diaphragm is a different matter. In the South African sample, the vertebral level of the IVC is equally distributed between T8, T9 and T10 (median value of T9), as opposed to T11 for the European sample (Mirjalili et al. 2012) and T10 in the Chinese sample (Shen et al., 2016). The level where the esophagus passes through the diaphragm was higher in the South African sample (most frequently T9, median = T9/T10) compared to the Chinese and European samples (T11) (Mirjalili et al., 2012a Shen et al., 2016) and common anatomical descriptions (T10) (Moore et al., 2010; Sinnatamby, 2011; Standring, 2015).

Xiphisternal plane

The vertebral level of the xiphisternal joint in the South African sample (this study) was similar to European (Mirjalili et al., 2012a) and Iranian samples (Pak et al., 2016). The xiphisternal joint was mostly level with the T8/T9 intervertebral disc, the upper half of T9 followed by the lower half of T8. Whilst the European sample (Mirjalili et al. 2012a) revealed no sex differences, the xiphisternal joint was significantly higher in South African females (T9) than in males (T10) (this study) and significantly higher in Iranian males (T8) than females (T9) (Pak et al., 2016).

Subcostal plane

The subcostal plane is the horizontal plane level with the lowest points of the costal margins intersecting the body of L3 and corresponds to the origin of the IMA (Ellis and Mahadevan 2010, Standring, 2015). Slightly higher levels, at the lower half of L2 or the upper half of L3 have been reported in historical studies (Anderson 1892), for a European sample (Mirjalili et al., 2012c) and a Turkish sample (Uzun et al., 2016) The level of the subcostal plane was even higher for the South African sample (this study), mostly at the L1/L2 intervertebral disc with the most inferior level at the L2/L3 intervertebral disc. Because the subcostal plane can be found at a more superior level in the Turkish (Uzun et al., 2016) and South African (current study) populations, this could explain why the origin of the IMA was found to be inferior to the plane in most of these cases (Turkish = 59%, South African (current study) = 84%).

Conclusion

A good knowledge of the thoracic surface anatomy is required when conducting clinical examinations, interpreting diagnostic images or performing interventional procedures or surgery. Our results confirm that surface anatomical planes and landmarks are not static. Clinicians need to accommodate for the range of normal variation that is present. Teaching anatomy in the pre-clinical years should include possible sex, postural and population specific variation.

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CONFLICT OF INTERESTS

There is no conflict of interest to declare by any of the authors.

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LIST OF TABLES

Table 1: Vertebral level of the sternal angle plane and position of the azygos vein/SVC junction and the bifurcation of the trachea and pulmonary trunk in relation to this plane.

	Total sample	**Females**	**Males**
N	75	42	33
Vertebral level			
Median	T4/T5	T4/T5	T4/T5
Range	Upper T3 - Lower T6	Lower T3 - Lower T6	Upper T3 - Upper T6
Frequency	Lower T4 (23%)	Lower T4 (26%)	Upper T4 (21%)
Azygos vein / SVC			
Frequency	Within 10 mm (55%)	Within 10 mm (59%)	Within 10 mm (50%)
Distance	5.7 mm Inferior	1.8 mm Inferior	10.8 mm Inferior
Tracheal bifurcation			
Frequency	Inferior (60%)	Inferior (48%)	Inferior (76%)
Distance	13.5 mm Inferior	8.1mm Inferior	20.4 mm Inferior
Pulmonary trunk			
Frequency	Inferior (76%)	Inferior (63%)	Inferior (94%)
Distance	19.5 mm Inferior	12.9 mm Inferior	28.0 mm Inferior

Table 2: Relationship of the formation of the left and right BCV to the ipsilateral sternoclavicular joint (most common frequency in bold).

	Total sample	**Females**	**Males**
N	**75**	**42**	**33**
Left BCV			
Posterior	35%	37%	33%
Superolateral	**41%**	**39%**	**42%**
Lateral	18%	16%	21%
Superior	6%	8%	3%
Right BCV			
Posterior	25%	18%	**33%**
Superolateral	**37%**	**45%**	27%
Lateral	33%	35%	30%
Superior	6%	3%	9%

Table 3: Position of the origin of the SVC and the SVC/RA junction in relation to the ribs.

	Total sample	Females	Males
N	75	42	33
SVC			
Median	Rib 1 CC	Rib 1 CC	Rib 1 CC
Range	Rib 1 CC - Rib 2 CC	Rib 1 CC - Rib 2 CC	Rib 1 CC - Rib 2 CC
Frequency	Rib 1 CC (78%)	Rib 1 CC (80%)	Rib 1 CC (78%)
SVC/RA			
Median	Rib 3 CC	Rib 3 CC	Rib 3 CC
Range	Rib 1 ICS - Rib 4 ICS	Rib 1 ICS - Rib 4 ICS	Rib 2 CC - Rib 4 ICS
Frequency	Rib 3 CC (45%)	Rib 3 CC (37%)	Rib 3 CC (59%)

Table 4: Position of the cardiac apex to the anterior thoracic wall and distance of this point from the midline.

	Total sample	Females	Males
N	73	41	32
Median	Rib 5 ICS	Rib 5 ICS	Rib 5 ICS
Range	Rib 3 ICS - Rib 7 CC	Rib 3 ICS - Rib 6 ICS	Rib 4 ICS - Rib 7 CC
Distance (mm)	81.3 ± 12.8	80.6 ± 11.8	82.1 ± 14.0

Table 5: Summary of the level through which thoracic structures pass through the diaphragm.

	Total sample	Females	Males
N	76	42	34
IVC			
Median	T9	T9	T10
Range	T7-T11	T7-T10/T11	T8-T11
Frequency	T8, T9, T10 (22%)	T8 (34%)	T10 (30%)
Esophagus			
Median	T10	T9/T10	T11
Range	T8/T9 - T12	T8/T9 - T11/T12	T9-T12
Frequency	T9 (27%)	T9 (44%)	T11 (34%)
Aorta			
Median	T12	T12	T12
Range	T11-L1	T11-T12/L1	T11-L1
Frequency	T12 (53%)	T12 (49%)	T12 (58%)

Table 6: Comparison of the level and position of thoracic structures.

	Vertebral level	**Azygos vein / SVC junction**	**Tracheal bifurcation**	**Pulmonary trunk bifurcation**
Chukwuemeka *et al.*, 1997	Upper T5	↓	↓	-
Mirjalili *et al.*, 2012a	T4/T5	↓	↓	↓
Shen *et al.*, 2016	T4/T5	↓	↓	↓
Uzun *et al.*, 2016	T4/T5	↓	↓	↓
Current study	T4/T5	Within 10 mm	↓	↓

Key: ↑ = superior & ↓ = inferior to the sternal angle plane

Table 7: Comparison of the levels that the IVC, esophagus and aorta pierce the diaphragm.

	IVC	Esophagus	Aorta
Mirjalili *et al.* (2012a)	T11 (38%)	T11 (47%)	T12 (48%)
Shen *et al.* (2016)	T10 (39%)	T11 (42%)	T12 (54%)
Current study	T8, T9, T10 (22%)	T9 (27%)	T12 (53%)