Original Article

Retrospective Analysis of Adult Thoracic Surface Anatomy in Indian Population using Computed Tomography Scans

Shallu Garg, Ajay Gulati[1], Anjali Aggarwal, Tulika Gupta, S. Ali Mirjalili[2], Daisy Sahni

Departments of Anatomy and [1]Radiodiagnosis and Imaging, Postgraduate Institute of Medical Education and Research, Chandigarh, India, [2]Department of Anatomy and Medical Imaging, Faculty of Medical and Health Sciences, University of Auckland, Auckland, New Zealand

Abstract

Introduction: Recent studies on human surface anatomy observed inconsistencies in standard surface markings from that given in contemporary anatomy texts, particularly in thoracic surface landmarks. The present study was conducted to reevaluate the thoracic surface anatomy of adults of Indian origin which has not been done so far and compare the observations with the descriptions obtained from other population groups. **Material and Methods:** The thoracic surface anatomy was analyzed in 100 thoracoabdominal computed tomography scans of the Indian population. **Results:** It was observed that the positions of the xiphisternal joint, sternal angle, central veins, apex of lungs, cardiac apex, and dome of the diaphragm were within the normal limits with slight deviations from that described in standard anatomy texts. However, certain landmarks showed high degree of difference among the races as well as from the descriptions of the textbooks such aortic arch, bifurcations of the trachea and pulmonary trunk, inferior border of right and left lung adjacent to the vertebral column, and vertebral level of inferior vena cava piercing the diaphragm. **Discussion and Conclusion:** The surface anatomical landmarks of the thorax are not static, and there is a need to accommodate for a range of values than the constant markings. The relationship of the thoracic structures with the overlying surface landmarks were more variable in relation to vertebral levels than the costal references.

Keywords: *Cardiac apex, central veins, diaphragm, lungs, sternal angle*

Introduction

Surface anatomy defines the relationship of the surface landmarks to the underlying deeper structures. To locate the anatomical structures under the skin with reference to palpable surface features is a core clinical skill,[1] precise understanding of which is invaluable in the clinical assessment of a patient, in interventional procedures, and in the interpretation of radiological imaging.[2]

Surface anatomy and surface markings are integral components of medical curriculum, aims at preparing students for clinical examination of patients[3] and provide important bridges between the laboratory and the clinic. Surface anatomy is certainly of value in helping students learn human anatomy as shown by the success of body painting as a learning tool.[4] Given the importance of surface anatomy, educational resources need to be more consistent. Our current understanding on this topic is largely derived from the cadaveric studies and measurements recorded decades ago, with all the limitations of distortion from embalming and positioning. Recent studies on human surface anatomy in different races using modern cross-sectional imaging techniques have documented major inconsistencies in standard surface markings from that given in contemporary anatomy texts.[5-9] According to their findings, although many surface landmarks are valid, however, variations with respect to age, sex, and particularly population were observed.

Knowledge of the surface anatomy of intrathoracic structures and the level of the diaphragm based on the surface landmarks is useful for interventional procedures, such as tube thoracostomy and for placing the thoracic incisions to provide the best access to the pulmonary hila, trachea, or great vessels.[2] The present study was conducted to reevaluate the thoracic surface anatomy of adults of Indian origin which has not been done so far and compare the observations with the descriptions obtained from other population groups.

Material and Methods

One hundred thoracoabdominal computed tomography (CT) scans (66 males

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Address for correspondence:
Dr. Anjali Aggarwal, Department of Anatomy, Postgraduate Institute of Medical Education and Research, Chandigarh - 160 012, India.
E-mail: anjli_doc@yahoo.com

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and 34 females) with the mean age of the patients 45.7 years, (range 20–80 years) performed in the Department of Radiology of our institute for various clinical indications were analyzed to determine the thoracic surface anatomy. All patients were of Indian origin. The CT examinations were performed on 128-MDCT dual-source scanner (Somatom Definition Flash, Siemens Healthcare, and Germany). The following technical parameters were used: pitch – 0.6, gantry rotation time - 0.5 seconds, and thickness of 5 mm. Scans of patients were acquired with intravenous contrast in the supine position, at end-tidal inspiration and with the arms abducted. The dose of intravenous contrast medium was calculated according to the patient's physical characteristics and clinical condition. CT postprocessing of data and image reconstructions was performed on dedicated workstation (Syngo Multimodality Workplace 2008A; Siemens). Scans of patients with kyphosis, scoliosis, abnormal lordosis, distorting space-occupying , and organomegaly were excluded from the analysis. Plane of sternal angle and xiphisternal joint with respect to vertebrae were assessed. Positions of important intrathoracic structures in relation to commonly practiced surface landmarks such as sternal angle and vertebrae, costal cartilage (CC), sternocostal joint, and clavicle were also studied as shown in Figure 1.

Statistical analysis

Means and standard deviations were calculated for continuous data. Comparisons between groups/measurements (i.e., left versus right, male versus 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.

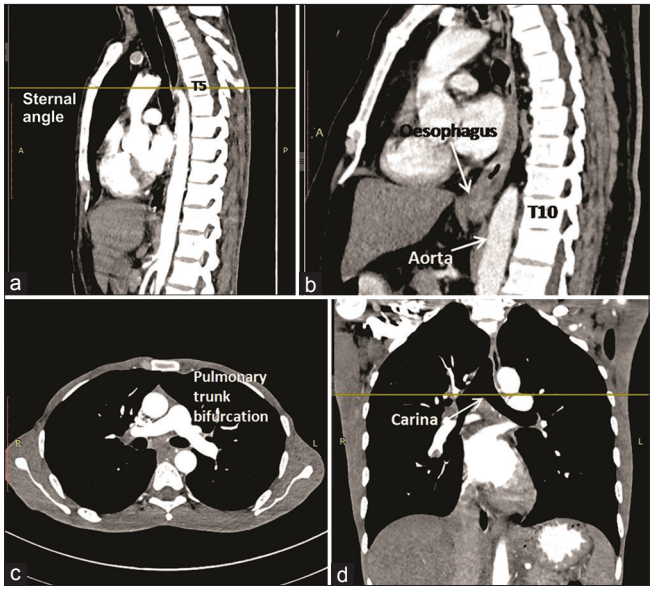

Figure 1: Computed tomography images showing (a) Vertebral level of the sternal angle (T5) identified in sagittal scan. (b) Vertebral level at which the esophagus and aorta passed through or behind the diaphragm determined in sagittal projections. (c) Pulmonary trunk bifurcation identified in axial scans. (d) Carina of tracheal bifurcation identified in coronal scans. (T, Thoracic vertebra)

Ethical approval

This study was approved by the Institutional Ethics Committee (No: NK/3654/Study/561).

Results

Sternal angle and its relationship to associated structures

The distribution of frequencies of vertebral levels of sternal angle, tracheal bifurcation, azygous vein/superior vena cava junction (azygos/SVC junction), pulmonary trunk bifurcation, and summit of aortic arch and xiphisternal joint, in all the 100 scans, is shown in Figure 2.

Analysis of data revealed that the vertebral plane of sternal angle varied widely from T3/4 to T6/7 intervertebral disc, though the most common vertebral level of the sternal plane was T4/5 intervertebral disc (35% of adults). However, it was observed that in >two-third of cases (82%), the plane of angle was between T4/5 and T5/6 intervertebral disc. Likewise, two more structures, the tracheal bifurcation and the azygos/SVC junction, were also lying between T4/5 and T5/6 intervertebral disc in 72% and 71% cases, respectively. There were no statistically significant gender differences in the observations ($P > 0.05$).

Vertebral plane of summit of the concavity of aortic arch too showed a wide variation from upper T2 (UT2) to T4/5 intervertebral disc. However, the most common vertebral level of aortic arch was T3/4 intervertebral disc (41%). Similarly, the vertebral level of pulmonary trunk bifurcation ranged from T3/4 to lower T7 (LT7), although in 58% adults, it was lying between T5/6 intervertebral disc to UT6 [Figure 2].

The exact relation of tracheal bifurcation, aortic arch, azygos/SVC junction, and pulmonary trunk bifurcation to the sternal plane are presented in Table 1. The concavity of the aortic arch was above the sternal plane in most of the cases (89%, $P < 0.0001$) at a mean distance of 3.05 ± 1.74 cm and pulmonary trunk bifurcation was lying more commonly below the sternal plane (73%, $P < 0.0001$) at an average distance of 1.95 ± 1.64 cm below the sternal plane. Within 10 mm of sternal plane, the tracheal bifurcation was present in 46%, termination of the azygos vein into the SVC in 62% and pulmonary trunk bifurcation in 32% of scans. Vertebral level of sternal angle was positively correlated with the tracheal bifurcation ($r = 0.521$; $P = 0.001$) and pulmonary trunk bifurcation ($r = 0.597$; $P = 0.001$).

Xiphisternal joint

The distribution of vertebral level of the xiphisternal joint is depicted in Figure 2f. The horizontal plane through the

Table 1: Relationship between the sternal angle and the major anatomical structures

	At the sternal angle (%)	Above sternal angle (mean distance from angle in cm)	Below sternal angle (mean distance from angle in cm)	Mean distance (cm) Above (+)/below (−) sternal angle (range)
Tracheal bifurcation	31	23% (1.75)	46% (1.90)	−0.64 (+2.7-−3.26)
Aortic arch	7	89% (3.05)	4% (1.58)	+2.87 (+5-−2.7)
Azygos/SVC junction	38	30% (1.39)	32% (1.30)	−0.015 (+2.8-−2.6)
Pulmonary trunk bifurcation	19	8% (1.98)	73% (1.95)	−1.57 (+1.9-−4.4)

SVC=Superior vena cava

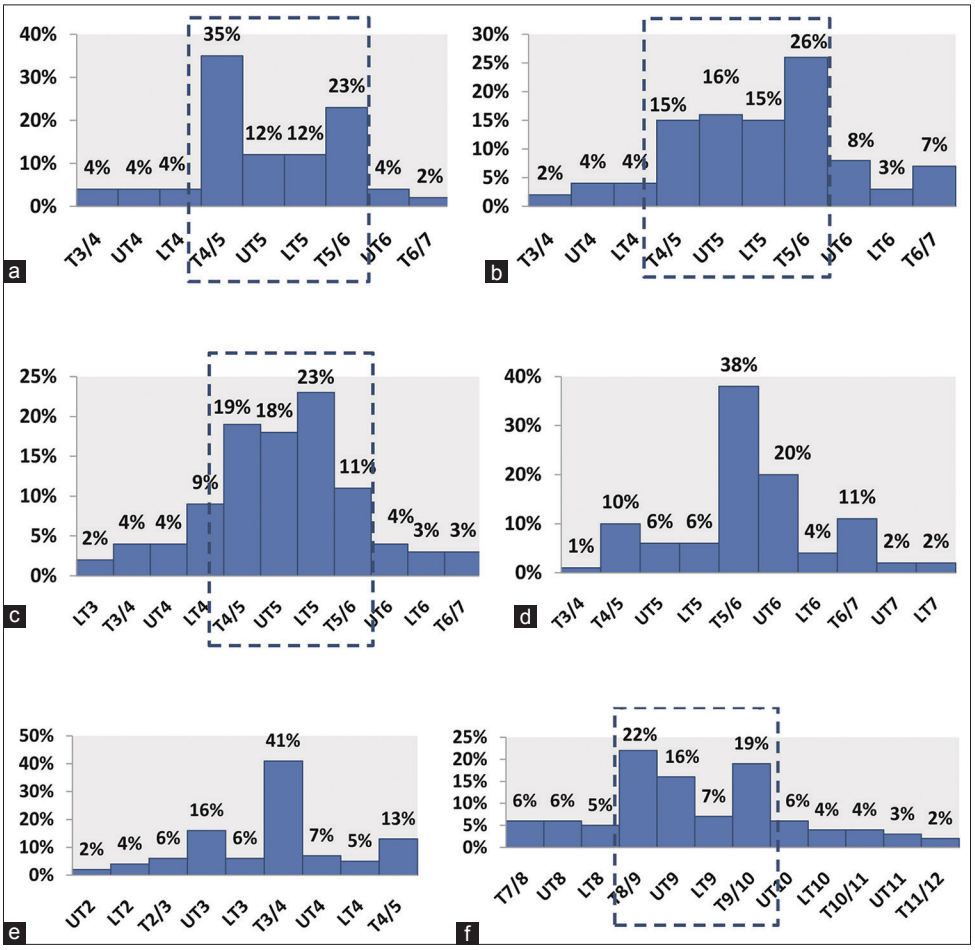

Figure 2: Frequency of distribution of vertebral levels of (a) Sternal angle. (b) Tracheal bifurcation. (c) Azygos/superior vena cava junction. (d) Pulmonary trunk bifurcation. (e) Summit of aortic arch. (f) Xiphisternal joint. X-axis represents vertebral level and Y-axis represents the frequency (U: Upper, L: Lower,/: Intervertebral disc, T: Thoracic vertebra)

xiphisternal joint most commonly extended from T8/9 intervertebral disc to T9/10 intervertebral disc (64%) in both males and females.

Central veins

The origin of the brachiocephalic vein (BCV) in relation to ipsilateral sternoclavicular joint was most commonly lying behind the joint (48% on the right and 58.6% on the left) or lateral (43.8% on the right and 34.6% on the left) to the joint, with no significant gender differences. The distribution of cranial and caudal levels of SVC in reference to CCs and anterior intercostal spaces (ICS) is shown in Figure 3a and b. Formation of SVC (cranial end of SVC) was mainly lying behind the first right CC and first ICS in 86% of adults and was partially overlapped by manubrium in 71% of scans. The SVC/right atrial junction (SVC/RA junction; caudal end of SVC) most commonly extended from the right third CC to 4th CC in 79% of adults. There were no significant gender differences in SVC origin (P = 0.65) or the SCV/RA junction (P = 0.81).

Cardiac apex

The position of the cardiac apex varied from 4th to 6th rib. It was at the level of 5th rib (49%) or 5th ICS (20%) anteriorly in maximum number of cases [Figure 3c]. The cardiac apex was positioned on an average 7.72 ± 1.37 cm to the left of midline (range 4.56–10.62 cm). There were no significant gender or age differences.

Lungs

The apex of the right lung was lying posterior to the medial third of the clavicle in 56 scans (with 22% crossing above the clavicle at a mean distance of 1.57 cm) and medial end of the clavicle in 40 scans (with 18% crossing above the clavicle at a mean distance of 1.27 cm). Similarly, the apex of the left lung was lying posterior to the medial third of the clavicle in 52 scans (with 20% crossing above the clavicle at a mean distance of 2.38 cm) and medial end of the clavicle in 32 scans (with 19% crossing above the clavicle at a mean distance of 1.56 cm). The anterior inferior border of the lung in midclavicular line was most commonly at the level of 6th rib (32, 51.6%) on the right and 6th rib (29, 46.7%)/7th rib (23, 37%) on the left [Figure 4a]. The anterior inferior border of the right lung was higher than the left lung in both males and females. The level of the posterior inferior border of both the lungs adjacent to the vertebral column ranged from T9/10 intervertebral disc to T12/L1 intervertebral disc. It was most commonly alongside the T11/12 intervertebral disc followed by T12 intervertebral disc in both the lungs [Figure 4b]. There were no significant gender and age differences.

Diaphragm

The costal level of the summit of dome of the diaphragm ranged from 3rd to 6th rib on the right side and 4th to 6th rib on the left side. On the right side, the dome was most commonly at the level of 5th rib (29%) followed by 4th rib (19%), and on the left, it was lying one rib lower, at the level of 5th rib in 40% and 6th rib in 24% of cases [Figure 5a].

Figure 5b illustrates the vertebral levels at which three main structures: inferior vena cava (IVC), esophagus, and aorta traversed through the diaphragm. The level of IVC varied from as high as UT7 vertebra to T11/12 intervertebral disc; however, most commonly it traversed through the diaphragm at the level of T9/10 intervertebral disc (26%) in both males and females. The esophagus and aorta traversed most commonly at T10/11 intervertebral disc (32%) and T11/12 intervertebral disc (41%) respectively.

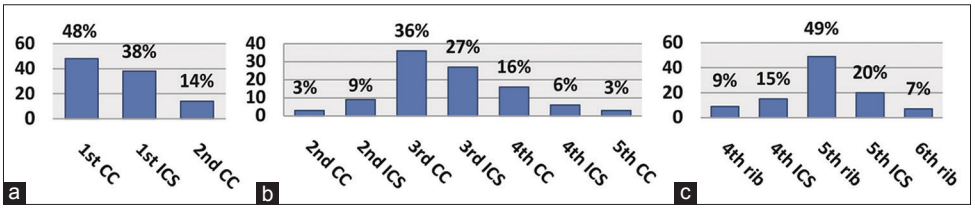

Figure 3: Frequency of distribution in reference to costal cartilage and intercostal space of the (a) Formation of superior vena cava. (b) Superior vena cava /Right atrial junction. (c) Cardiac apex

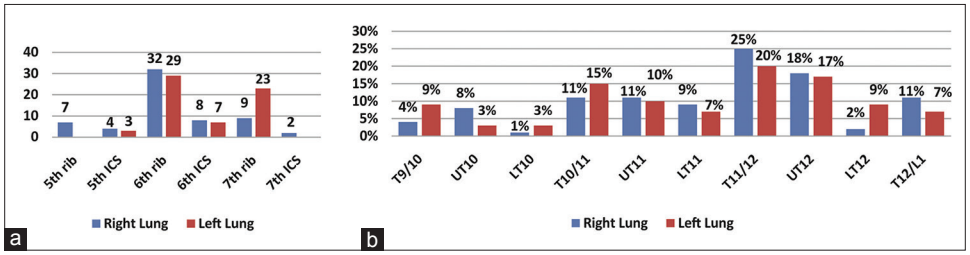

Figure 4: Frequency of distribution of (a) Costal level of anterior inferior border of the right and left lung at the level of midclavicular line. (b) Vertebral level of posterior inferior border of the right and left lung adjacent to the vertebral column. (ICS: Intercostal space, U: Upper, L: Lower, /: Intervertebral disc)

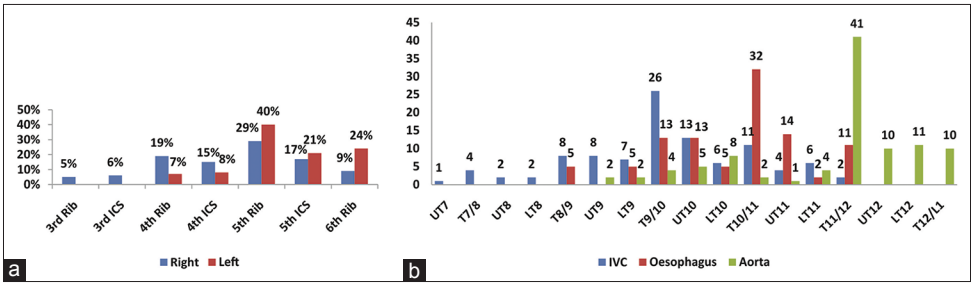

Figure 5: Frequency of distribution of (a) Costal level of the summit of dome of the diaphragm. (b) Vertebral level of passage of IVC, esophagus, and aorta through/behind the diaphragm. (ICS: Intercostal space, U: Upper, L: Lower, /: Intervertebral disc, IVC: Inferior vena cava)

Correlation with age

There was a positive correlation between age and surface anatomy of sternal angle (r = 0.94; P = 0.05), cranial (r = 0.547; P = 0.03) and caudal levels of SVC (r = 0.519; P = 0.04) [Table 2].

Discussion

The observations of the present study differed from that reported in other population studies [Tables 3-5], though the surface anatomy in reference to costal skeleton was strikingly congruent with the textbook description [Table 4].

The vertebral level of the sternal plane in different population studies was most commonly intersecting the T4 vertebra or T4/5 intervertebral disc coinciding with the anatomy textbooks [Table 3]. In our study, the vertebral level of the sternal angle was seen to change with age. In the early decades of life, the level coincided with the anatomical texts; however, with each increasing decade, slight downward shift was observed. Similar trend was noticed in the Chinese population.[6]

According to most of the studies, the tracheal bifurcation, aortic arch, azygos/SVC junction, and pulmonary trunk bifurcation lie below the level of the sternal plane. In our study of the Indian population, the azygos/SVC junction was lying most commonly at the level of sternal angle, although its position varied from 2.8 cm above to 2.6 cm below the sternal plane. Tracheal bifurcation and pulmonary trunk were lying most commonly below the sternal plane. Similar observations have been reported in the African population[9] [Table 3].

According to major anatomy texts,[10-12] the vertebral level at which the IVC, esophagus, and aorta pass through/behind the diaphragm is T8, T10, T12 vertebra, respectively, indicating difference of two vertebrae between these structures. Observations of the present and all the other studies have depicted that the vertebral level at

Table 2: Age-related changes in the surface anatomy of sternal angle and superior vena cava

Vertebral levels of sternal angle	Mean age (years)	Position of SVC formation	Mean age	Position of SVC/RA junction	Mean age (years)
T4/5 intervertebral disc	33.1	1st CC	41	2nd ICS and above	35
Upper T5	50.8	1st ICS	48	3rd CC - 3rd ICS	41.5
Lower T5	57.1	2nd CC	60	4th CC - 4th ICS	61.9
T5/6 intervertebral disc	65.4	-	-	-	-

T=Thoracic vertebra, SVC=Superior vena cava, RA=Right atrium, CC=Costal cartilage, ICS=Intercostal space

Table 3: Vertebral level of various thoracic structures and their relation with sternal angle in different populations

	Indian (current study)	European[5]	Chinese[6]	Turkish[7]	Iranian[8]	South African[9]	Text book[10-12]	Proposed range
Sternal angle	T4/5 (35%) T5 (24%)	T4 and T4/5 (48%)	T4 and T4/5 (51%)	T4 (35%)	-	T4 (23%)	T4/5 or IB T4	T4-T4/5
Tracheal bifurcation	T5/6 (26%) ↓ SA (46%)	T6 (46%) ↓ SA (93%)	T5 (40%) or T6 (35%) ↓ SA (91%)	T5 or T5/6 (57.4%) ↓ SA (80%)	-	↓ SA (60%)	T4/5 or IB T4	T5-T6 (one vertebra below SA)
Aortic arch	T3/4 (41%) ↑ SA (89%)	T5 (55%) ↓ SA (62%)	T4/5 or T5 (62%) ↓ SA (50%)	T3-T4 (33%) At SA (59%)	-	-	T4/5 or IB T4	T3-T5
Pulmonary trunk bifurcation	T5/6 (23%) ↓ SA (73%)	T6 (28%) ↓ SA (96%)	T5/6 or T6 (56%) ↓ SA (97%)	T6 (42%) ↓ SA (95%)	-	↓ SA (76%)	T4/5 or IB T4	T5/6-T6 (below SA)
Azygous/SVC junction	T5 (41%) At SA (38%)	T5 (49%) ↓ SA (87%)	T5 (47%) ↓ SA (79%)	T5 (48%) ↓ SA (73%)	-	At SA (55%)	T4/5 or IB T4	T5 (at or slightly below SA)
Diaphragm openings								
IVC	T9/10 (26%)	T11 (38.3%)	T10 (39%)	-	T10 (62%)	T8, T9, T10 (20%)	T8	T10
esophagus	T10/11 (32%)	T11 (47.2%)	T11 (42%)	-	T11 (65%)	T9 (17%)	T10	T11
Aorta	T11/12 (41%)	T12 (47.9%)	T12 (54%)	-	T12 (88%)	T8 (16%)	T12	T12
Xiphisternal joint	T8/9 (22%) or T9/10 (19%)	T9 (46%)	T8/9 (19%) or T9 (31%)	-	T9 (56%) T8 (37%)	T 8/9 (20%) T9 (17%)	T9	T8/9-T9

SA=Sternal angle, /=Intervertebral disc, IB=Inferior border, SVC=Superior vena cava, T=Thoracic vertebra, IVC=Inferior vena cava, ↓=below sternal angle, ↑=above sternal angle

Table 4: The costal level of various thoracic structures in different populations

Population	Formation of SVC	SVC/right atrial junction	Cardiac apex	Dome of diaphragm	
				Right	Left
Indian (present study)	1st CC (48%) and 1st ICS (38%)	3rd CC (36%) and 3rd ICS (27%)	Left 5th rib (49%) Left 5th ICS (20%)	5th rib (29%) 5th ICS (17%)	5th rib (40%) 6th rib (24%)
European[5]	2nd CC (42%) 1st ICS (36%)	4th CC (32%) 5th CC (22%)	Left 5th ICS (42%) 6th rib (29%)	5th ICS (27%)	6th rib (27%)
Chinese[6]	1st ICS (62%)	4th ICS (41%)	Left 5th ICS (43%)	5th ICS (30%) 6th rib (29%)	6th rib (29%) 6th ICS (25%)
Iranian[8]	1st ICS (52%)	3rd ICS (27%)	Left 5th ICS (71%)	5th CC (71%) and 4th ICS (25%)	5th ICS (35%) 6th CC (30%)
South African[9]	1st CC (78%)	3rd CC (45%)	Left 5th ICS (41%)	-	-
Text book description[10,11]	1st CC	3rd CC	Left 5th ICS (1.25 cm inside the midclavicular line)	4th ICS or 5th rib	5th rib or 5th ICS
Proposed range	1st CC-1st ICS	3rd CC-4th ICS	Left 5th rib-5th ICS	5th rib-5th ICS	5th rib-6th rib

CC=Costal cartilage, ICS=Intercostal space, SVC=Superior vena cava

Table 5: Surface marking of the lungs

Structure	Lung	Indian population (present study)	European population[5]	Chinese population[6]	Text book description[10,11]	Proposed range
Apex	Right lung	Behind medial 1/3rd clavicle (56%)	Behind medial 1/3rd clavicle	-	Behind medial 1/3rd clavicle	Behind medial 1/3rd clavicle
	Left lung	Behind medial 1/3rd clavicle (52%)	Behind medial 1/3rd	-	Behind medial 1/3rd clavicle	Behind medial 1/3rd clavicle
Inferior border of lung in midclavicular line	Right lung	6th rib (62.5%)	6th ICS (39%) 7th rib (29%)	6th ICS (40%) 6th rib (28%)	6th rib	6th rib-7th rib
	Left lung	6th rib (46.7%) or 7th rib (37%)	5th rib (31%) 5th ICS (24%)	5th rib (25%) 5th ICS (18%)	6th rib	5th rib-6th rib
Inferior border of lung adjacent to vertebral column	Right lung	T11/12 (25%) or T12 (20%)	T12 (33%)	T12 or T12/L1 (50%)	T10	T11/12-T12/L1
	Left lung	T11/12 (20%) or T12 (26%)	T12 (37%)	T12 or T12/L1 (51%)	T10	T11/12-T12/L1

/=Intervertebral disc, ICS=Intercostal space, T=Thoracic vertebra

which the IVC, esophagus, and aorta pass through/behind the diaphragm were most commonly one vertebra down relative to each other and most commonly at the level of T10, 11, and 12 vertebra, respectively. Xiphisternum lies at the level of T8/9–T9 vertebra in all the population studies [Table 3].

Central veins

The right and left BCVs of the Indian population was located directly posterior to the ipsilateral sternoclavicular joint similar to that recorded in Iranian[8] and European[5] populations and confirming the descriptions given in medical texts.[10-12] In contrast, in the South African[9] and Chinese[6] population, it was located superolateral or lateral to the ipsilateral sternoclavicular joint. There were no gender related differences in the present and the previous populations.

The surface anatomy of the cranial and caudal end of SVC in reference to costal skeleton was congruent with the text book description in the Indian and South African population[9] but differed from that reported in other population studies [Tables 4]. The SVC/RA junction was age related in our population and that of Chinese population.[6] There were no gender-related differences in both the levels, in the Indian and other population studies except that SVC/RA junction was significantly higher in females of European population.[6]

Cardiac apex

In most of the population studies, cardiac apex was most commonly located at 5th ICS which is congruent to the medical texts [Tables 4]. However, in the present study (Indian population), cardiac apex was located mostly at 5th rib followed by 5th ICS and was more toward the midline (77 ± 13.7 mm to the left of midline) than the other population studied, including African[9] (81.3 ± 12.8 mm), Chinese[6] (83 mm), and European[5] (87 ± 10 mm) populations.

Diaphragm

In the present population, the dome of the diaphragm at end-tidal inspiration in the supine position was at 5th rib or

5th ICS on the right and 5th or 6th rib on the left, comparable to the anatomy texts [Table 4]. In contrast, in the European population,[5] the dome was slightly lower at the level of 5th ICS on the right and 6th rib on the left.

Lungs

The apex of the lung was most commonly posterior to the medial third of the clavicle in the Indian and European populations which is in agreement with the common medical textbooks [Table 5]. The surface marking of the inferior border of the lung in quiet respiration is represented by a line passing through the 6th rib inthe midclavicular line, the 8th rib in the midaxillary line, 10th rib at the scapular line, and T10 vertebra posteriorly.[10-12] There are few studies mentioning surface marking of inferior border of the lung which according to the present findings, the rule of 6, 8, and 12 given by Mirjalili *et al*.[5] would be more accurate than 6, 8, and 10 given in textbook descriptions.

Conclusions

From all these elaborative studies, it is confirmed that surface anatomical landmarks are not static and there isa need to accommodate for a range of values than the constant markings. Incorporating these findings into the texts would help clinicians to improve their clinical skills. There were no statistically significant gender differences found in the thoracic surface anatomy in the present population and most of the other population studies.

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Conflicts of interest

There are no conflicts of interest.

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