How Far Is the Sternal Angle from the Mid-right Atrium?

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BACKGROUND: The central venous pressure (CVP) is commonly estimated at the bedside by measuring the height of the jugular venous pressure (JVP) relative to the sternal angle. Determining the CVP from this measure requires that the distance from the sternal angle to the level of the mid-right atrium be known. Classical clinical teaching quotes this distance as 5 cm, invariable between patients, and invariable with changes in the elevation of the patient's head. The validity of these JVP characteristics has been questioned.

OBJECTIVES: To measure the distance from the sternal angle to the level of the mid-right atrium (SA-RA) and determine if the SA-RA distance varies with patient position.

METHODS: Cross-sectional study conducted at a single-center teaching hospital on ambulatory patients undergoing computed tomography of the chest.

RESULTS: One hundred sixty patients were included. The median SA-RA distance with the patient lying supine was 5.4 cm (interquartile range, 4.7 to 6.1). Using geometric calculations to estimate the SA-RA distance when the patient's torso was elevated above the supine position, the median SA-RA distance was calculated to be 8 cm, 9.7 cm, and 9.8 cm at 30, 45, and 60 degrees elevation respectively. The SA-RA distance varied extensively between patients and was independently associated with smoking, age, and antero-posterior chest diameter.

CONCLUSIONS: The distance from the sternal angle to the level of the mid-right atrium varies considerably between individuals and with patient position. When using the JVP to calculate the CVP, physicians need to consider specific patient factors and the patient's position.

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The jugular venous pressure (JVP) is an important component of the bedside assessment of intravascular volume status.¹ Clinicians use the JVP to quickly and noninvasively estimate a patient's central venous pressure (CVP). The JVP is measured as the vertical distance from the top of the column of blood in the internal jugular vein to a zero point, most commonly taken to be the level of the right atrium.²

There has been much controversy in the literature and among clinicians regarding the most appropriate method of examining the JVP³⁻⁶ as well as the utility of this bedside test.⁷⁻¹⁰ One of the most important elements in measuring the JVP and using it to estimate the CVP is identifying a uniform and easily reproducible external reference point that most reliably reflects the zero point.^{1,11} The mid-right atrium is assumed to be the zero point because it has the lowest fluctuations of hydrostatic pressure within the venous system. Therefore, the location of the mid-right atrium is essential for determining the CVP. Externally, the mid-right atrium is represented by the phlebostatic axis, which is the junction of the fourth intercostal space and midpoint of the antero-posterior (AP) diameter.^{12,13} However, this has not been extensively corroborated.

The sternal angle has been the most widely used external reference point.^{5,7,11,14,15} It is the most easily and reproducibly identified external landmark, even though it may not be the most accurate.³ The CVP is most commonly estimated by measuring the vertical height from the top of the jugular venous pulsation to the sternal angle. This vertical height is then added to the distance from the sternal angle to the level of the mid-right atrium (SA-RA) to obtain CVP in cm H₂O. The SA-RA distance has most widely been cited as 5 cm.^{7,11,12,14,16-18} In addition, many references claim that this distance does not vary when patients are elevated above the horizontal.^{5,7,11,17}

Clinicians have questioned these concepts regarding the SA-RA distance. Two studies, in which central veins were cannulated to permit accurate measurement of CVP relative to the sternal angle, found that measurements in the supine position differed significantly from those done with the subjects sitting at 45 degrees above the horizontal.^{3,19} Both Sapira¹⁶ and McGee² geometrically argued that, contrary to common teaching, SA-RA distance should vary with patient position. Others have echoed this sentiment.⁴ Several studies that have compared the bedside assessment of the JVP with an internal jugular vein catheter^{3,19} have consistently found that the former underestimates the CVP. McGee suggests that this underestimation is due to the exaggerated postural fall of the venous pressure when the patient is in the upright position.²

To our knowledge, no study has rigorously assessed the SA-RA distance. The purpose of this cross-sectional study was to measure the SA-RA distance in a broad group of patients to determine if it indeed is 5 cm. Using geometric calculations, we explored whether the SA-RA distance changed with patient position. Finally, we wanted to determine which patient factors influenced the SA-RA distance.

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METHODS

Choice of Imaging Technology

To calculate the distance from the sternal angle to the level of the mid-right atrium, we required an imaging technology that could reliably identify the sternal angle and the junction of the superior vena cava with the right atrium. We also needed to be able to measure the AP diameter as well as the vertical distance from the sternal angle to the level of the mid-right atrium in the supine position. These measurements had to be perpendicular to the horizontal plane for accuracy and for use in the proposed geometric model. Computed tomography (CT) met each of these requirements and was used for this study. Echocardiography could have been used to measure these distances, but we could not ensure that its measures were truly perpendicular to the horizontal plane.

Patient Recruitment

All ambulatory patients undergoing CT of the chest at the Ottawa Hospital–Civic Campus between 3 April 1998 and 30 September 1998 were invited to participate in the study. The hospital's institutional review board approved the study. Patients were provided a 1-page summary that explained the study's purpose, and informed consent was obtained. Patients who participated in the study completed a questionnaire that elicited their age, gender, height, weight, smoking status, and whether they had undergone previous thoracic surgery. Patients smoking >10 cigarettes/day for at least a 10-year period of time were classified as "smokers." The ordering physician cited the indication for the CT on the requisition.

Patients were excluded if they declined to participate, were unable to complete the questionnaire (because of language barrier or illness), had their CT after regular working hours, or their large body size prohibited the identification of required landmarks on the CT image. Patients with severe chest abnormalities, such as previous complete pneumonectomy, severe kyphoscoliosis, or severe mediastinal shift, were also excluded, because these malformations decreased the accuracy of our measurements.

Measurements

All CT scans were performed on a General Electric High Speed Advantage scanner (General Electric, Fairfield, Conn) with patients lying supine and the head supported in a standard head holder. Scans were obtained with the patient supine during breath-hold at the end of a usual inspiration. All measurements were obtained by the same CT technologist. The SA-RA distance for supine patients (Fig. 1A, line c) and the SA-RA distance for patients at 90 degrees (Fig. 1A, line d) were measured from the appropriate cuts at the scanner's work station. To identify the sternal angle on the CT, the level at which the second costal

cartilage joined the sternum was located. The central portion of the sternal angle has a higher attenuation than the sternal body or manubrium, because it lacks bone marrow, thereby making the angle readily identifiable.²⁰ The mid-right atrium was located as the midpoint between the anterior and posterior border of the right atrium 2 cm below the junction of the superior vena cava and the right atrium. Two centimeters was chosen because the average diameter of the right atrium is approximately 4 cm^{11,21} and the inferior border of the right atrium could not be reliably identified on CT imaging. Each patient's antero-posterior and transverse chest diameters were measured directly from the CT.

The SA-RA distance at 0 and 90 degrees was measured directly from the CT scan. This, of course, was done with the patient supine. The SA-RA distance at 90 degrees, therefore, did not consider movement of the heart when the patient stands. We used geometric

FIGURE 1. Distance from the sternal angle to the level of the mid-right atrium (SA-RA) at angle α . Patient is shown supine (A) and elevated to angle α (B). Lines a, b, and d were all measured directly from the CT scan. Line c was calculated as the difference of a and b. SA-RA is the distance from the sternal angle to the level of the mid-right atrium—the junction of L (A) and L (B). In A, SA-RA equals c. In B, SA-RA equals $\sin \alpha * (d + c(\tan(90-\alpha)))$. This equation is valid in all situations, including when the sternal angle is not in the same vertical plane as the mid-right atrium.

calculations to determine the SA-RA at 30, 45, and 60 degrees (Fig. 1B). This model did not consider changes of heart position within the mediastinum when the patient took a nonsupine position.

Analysis

We used univariate linear regression to determine the association between patient factors and SA-RA distance. Multiple linear regression with forward stepping variable selection ($\alpha = 0.05$ to enter) was used to determine the independent association of each patient factor with SA-RA distance at 45 degrees of elevation. Model fit was determined using jackknife residual plots to identify outlier observations. Eigenanalysis and variation inflation factors were used to exclude significant collinearity in the final model. The relative importance of each variable in the final model was determined comparing the standardized coefficients. First-level interaction between factors in the final model was explored using standard techniques.²² All analyses were conducted using SPSS Windows release 8.0.0 (SPSS Inc., Chicago, Ill).

RESULTS

Three hundred thirty-three outpatients underwent a CT scan of the chest during the study period. One hundred ninety-one of these patients agreed to participate, and 31 were excluded because of extreme chest deformities. This left 160 patients (50.7% of the original cohort) in the study. Study participants were middle-aged (median age 60, interquartile range [IQR], 50 to 70) and 52% were women. Their median height and weight were 168 cm (IQR, 158 to 177) and 70 kg (IQR, 60 to 81), respectively. Smokers comprised 58.8% of patients. One hundred (62.9%) scans were performed for the diagnosis or follow-up of malignancy, while 29 (18.1%) investigated diseases of the lungs and pleura.

The horizontal and vertical components of the SA-RA distance varied considerably between patients (Fig. 2). With the patient supine, SA-RA distance centered around 5 cm (median 5.4 cm; IQR, 4.6 to 6.1). With the patient elevated to 90 degrees however, the SA-RA distance was much greater than 5 cm (median 8.3 cm; IQR, 7.0 to 9.6). It should be noted that the SA-RA distance at 90 degrees was not measured in that position, but was measured from the CT scan with the patient supine (Fig. 1B, line d). Therefore, the SA-RA distance at 90 degrees did not take into account that the heart may change position in the mediastinum when the patient is elevated from the supine position. The SA-RA distances at 0 and 90 degrees were not associated with each other (Fig. 2).

Figure 3 presents the calculated SA-RA distance for various degrees of elevation of the torso above the horizontal. Measurements at 30, 45, and 60 degrees were calculated geometrically (Fig. 1B). The calculated SA-RA distance changed considerably when the patient's torso was elevated. The greatest increase in SA-RA

FIGURE 2. Association between vertical and horizontal components of SA-RA. Measurements of the horizontal and vertical components of SA-RA are displayed. These correspond to the sternal angle-right atrium distance with the patient at 0 and 90 degrees elevation, respectively. The distribution of each is summarized by the modified Tukey plots in which the inner rectangle extends from the 25th to the 75th percentile and is intersected by the median measurement. The outer rectangle indicates the 10th and 90th percentile while the lines extend from minimum to the maximum observation.

distance occurred when calculated at 30 degrees of elevation. At 30, 45, and 60 degrees elevation, none of the calculated SA-RA distances were 5 cm, the SA-RA distance measurement most commonly cited by physical examination references.^{7,11,14,16,17} Between 30 and 60 degrees elevation, the median calculated SA-RA distance was close to 8 cm.

Table 1 presents the association between patient characteristics and the SA-RA distance. Only results for 45 degrees are presented, since these associations were, with minor exceptions, consistent between positions. Each patient factor was significantly associated with the calculated SA-RA distance at the univariate level. The SA-RA distance was 1 cm greater for smokers and 0.8 cm less for women. The SA-RA distance increased as each continuous variable increased. AP chest diameter had the strongest association with the SA-RA distance, which increased by approximately 0.2 cm for every 1-cm increase in AP diameter.

FIGURE 3. Changes in SA-RA distance with changes in body position. Distributions for SA-RA distance are presented for various patient positions. The distributions are represented by modified Tukey plots in which the inner rectangle extends from the 25th to the 75th percentile and is intersected at the median measurement. The outer rectangle extends from the 10th to the 90th percentile with the whiskers extending to the minimal and maximal measurements.

Patient factors found to be independently associated with SA-RA distance included age, smoking status, and AP diameter (Table 1). Standardized coefficients (which remove the influence of each factor's unit of measurement from the coefficient estimate) showed that AP diameter and patient age had the strongest influence on SA-RA distance (standardized coefficients of 0.36 and 0.32, respectively). The multiple linear model fit the data well with only 1 observation having a standardized residual that exceeded 3. No concerning collinearity was noted, and the model explained 37.9% of variation in SA-RA distance.

DISCUSSION

To our knowledge, this is the most systematic assessment of commonly held—and commonly taught—beliefs regarding a common and important component of the physical examination. The SA-RA distance was found to be approximately 5 cm only in the supine position. Using geometric calculations, we found that this distance changed considerably when patients were elevated above the supine position. These measures varied extensively between patients. Smoking, increased age, and increased chest wall AP diameter were all independently associated with an increased SA-RA distance. When measuring the JVP to calculate the CVP, physicians need to consider these patient factors and the patient's position.

Our study confirms previous suspicions that SA-RA distance should vary between patients²³ and should vary with patient position.^{2,4,23} The variation that we found in the SA-RA distance with changes in patient position helps explain why Haywood et al.³ and Amoroso and Greenwood¹⁹ measured such different central venous pressures when patient positions were altered. Interestingly, the mean difference in SA-RA distance that we observed between 45 degrees and supine (4.3 cm) was almost identical to that observed by Haywood et al. (4.4 cm).³

Our findings support a number of previous observations regarding the utility of the JVP at the bedside. It is felt that the JVP reliably reflects CVP when right-sided pressures are elevated, such as with congestive heart failure, right ventricular infarction, cardiac tamponade, and constrictive pericarditis.^{8,18} This could reflect the large SA-RA distances that we calculated when patients were in a nonsupine position, which would require high CVPs for visualization of the JVP. A suggested rule of thumb has the JVP elevated if its bedside measurement is 3 cm above the horizontal from the level of the sternal angle.² Our results support this, since a JVP of 3 cm above the sternal angle indicates an approximate CVP of 11 cm H₂O, indicating an elevated right

Table 1. Association of Patient Characteristics and Distance from the Sternal Angle to the Level of the Mid-right Atrium (SA-RA)

Factor	Association with SA-RA		P Value Univariate/Multivariate
	Univariate (95% CI)	Multivariate (95% CI)	
Categorical			
Smoker*	1.04 (0.6 to 1.4)	0.59 (0.22 to 0.96)	.0001/.002
Gender†	−0.80 (−0.4 to −1.1)	—	.0001
Continuous			
Age, y	0.04 (0.03 to 0.05)	0.03 (0.02 to 0.04)	.001/.0001
Height, cm	0.03 (0.01 to 0.05)	—	.01/—
Weight, kg	0.02 (0.01 to 0.03)	—	.004
AP diameter of chest, cm	0.18 (0.13 to 0.24)	0.14 (0.09 to 0.20)	.0001/.0001
Transverse diameter of chest, cm	0.11 (0.05 to 0.17)	—	.001/—

* Smokers were coded as 1.

† Males were coded as 0, females were coded as 1.

The association between each patient factor and the distance from the sternal angle to the level of the mid-right atrium at 45 degrees elevation is presented. Similar results were achieved at the other patient positions. For univariate associations of continuous variables, the coefficient of the univariate linear regression (with 95% CI) is provided, indicating the amount SA-RA changed (in cm) when the factor changed 1 unit (in parentheses). Categorical variables are compared using Student's *t* test. All *P* values are 2-tailed. AP, antero-posterior.

atrial pressure, as Lewis suggested. Finally, the height of the JVP is felt to be particularly inaccurate for the diagnosis of hypovolemia.²⁴ Since the SA-RA distance is approximately 5 cm in the supine position, and increases with elevation of the patient's torso, lack of visualization of the JVP may be a normal finding. If the JVP is not visible above the sternal angle, it does not necessarily mean that the CVP is low.

We observed a strong association between smoking and SA-RA distance (Table 1). This association is possibly confounded by obstructive lung disease (OLD) that is a consequence of smoking. OLD can result in hyperinflation of the chest and increase the distance from the sternum to the mid-right atrium. This would increase the SA-RA distance and could explain why smoking was significantly and independently associated with a greater SA-RA distance.

We should highlight several potential weaknesses of our study. First, our study included only patients who had a CT of the chest. Many of these patients were ill with cancer or chronic lung disease. Although we cannot be certain that our findings externalize to other people, we found no significant differences in SA-RA distance in any position between patient groups with different referring diagnoses (i.e., cancer, lung disease, other). Second, our calculations did not consider that the heart may drop, relative to the sternal angle, when the patient is elevated from a supine position. Experiments in dogs have found that the heart drops up to 1 cm when they are held upright.²⁵ Therefore, our calculations for patients above supine likely underestimate the SA-RA distance.

Finally, the utility of our findings depends entirely on how well clinicians actually identify and measure the JVP. Interobserver agreement when measuring the JVP has been poor in some studies.^{11,26} This limits the reproducibility of the JVP as a measure of the CVP. Nevertheless, an accurate external reference point is a prerequisite for estimating CVP by the JVP. Understanding that the distance from the most widely used external reference point (the sternal angle) and the zero point (the mid-right atrium) is not always 5 cm should improve how clinicians use this measurement in their physical examination. Although the JVP is only 1 component of the intravascular volume status assessment, it is important that it be measured in an unbiased fashion. Knowing the distance from the sternal angle to the mid-right atrium is essential if the JVP is to be used for making decisions for patient care.

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