Use of vertebral body units to locate the cavoatrial junction for optimum central venous catheter tip positioning

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Abstract

Background: Central venous catheter (CVC) placement plays an important role in clinical practice; however, optimal positioning of the CVC tip remains a controversial issue. The objective of this study was to evaluate the use of vertebral body unit (VBUs), to locate the cavoatrial junction (CAJ), for optimal CVC tip placement based on chest radiography (CXR) using the carina as a landmark.

Methods: 524 patients who underwent coronary computed tomographic angiography (CTA) and CXR were included. The position of the CAJ was identified using VBUs, and the efficacy of VBUs for locating the CAJ with the carina as a landmark was analysed using multiple regression analysis. A VBU was defined as the distance between two adjacent vertebral bodies, including the inter-vertebral disk space.

Results: The mean (sd) distance from the carina to the superior CAJ was 54.3 (9.7) mm on CTA; the mean distance in VBUs at the level of the carina was 21.4 (1.7) mm on CTA and 22.6 (2.1) mm on CXR. The mean CAJ position was 2.5 VBUs below the carina on CTA and 2.4 VBUs below on CXR with 95% limits of agreement between −0.6 and +0.3.

Conclusions: The position of the CVC tip in relation to the carina can be described using the thoracic spine as an internal ruler, and the position of the CAJ in adults was reliably estimated to be 2.4 VBUs below the carina.

Clinical trial registration: KCT0001319.

Key words: central venous catheter; right atrium; superior vena cava; vertebra

CVC placement plays an important role in the management of critically ill patients; however, optimal positioning of the CVC tip remains a controversial issue. The US Food and Drug Administration recommends that ‘the catheter tip should not be placed in, or be allowed to migrate into the heart.’¹ ² The National Association of Vascular Access Networks and Infusion Nurses Society state that the tip should be located in ‘the lower one-third of the superior vena cava (SVC), close to the junction of the SVC and right atrium (RA).’³ ⁴ Malpositioning of the CVC tip can be lethal. Therefore, radiographic landmarks, such as the sixth thoracic vertebral interspace, inferior borders of the clavicles, the carina, and the right tracheobronchial angle have been used.⁵ ⁹ Few studies have addressed the relationships between radiographic landmarks and the CAJ.¹⁰⁻¹² Baskin and associates proposed the use of VBUs as an internal ruler for determining CVC tip location in adolescents and young adults.⁷

A VBU was defined as the distance between two adjacent vertebral bodies, including the inter-vertebral disk space. The
objective of this study was to evaluate the efficacy of VBUs for describing CVC tip location based on structures that are visible on chest radiography. In addition, the relationships between gender, age, BMI and the position of the CAJ measured in VBUs with regard to the carina were evaluated in an adult cohort.

Methods

This prospective study was reviewed and approved by the institutional ethics committee (Ethical Committee of Sungkyunkwan University, Samsung Changwon Hospital, approval number 2012-SCMC-024-00). Written informed consent was obtained from all participants.

The initial study population included 560 patients (70 men and 70 women from each decade of life from the fourth decade to age 70 and above), with suspected acute coronary syndrome, undergoing coronary CTA and upright CXR, at the Samsung Changwon Hospital from September 2012 to February 2013. The exclusion criteria applied were as follows: central vein or central airway invasion by lung cancer, destructive lung disease, and spine disease or a history of spine surgery. In total, 13 patients with lung cancer, 11 patients with destructive lung disease, and 12 patients with spine disease or a history of spine surgery were excluded. A flowchart of patient enrolment is shown in Fig 1.

Results are presented as frequencies (percentages) for categorical variables. Continuous variables are presented as the mean (SD) or as the median and range. The Student’s t-test or ANOVA was used to compare outcome variables between two or more groups. Correlations between the distance from the carina to the CAJ, the CAJ position in VBUs on CXR, and other variables (i.e. gender, age, height, weight, and BMI) were analysed using Pearson’s correlation method. Inter-rater reliability between the two investigators for the distance from the carina to the CAJ and the height of the vertebral bodies on CTA and CXR, were assessed using the intra-class correlation coefficient. Variables found to be significant were selected as potential confounders and included in a multiple regression model, to adjust for the influence of confounders. The Bland-Altman plot was used to evaluate coronary CTA and CXR reproducibility, to visualize the agreement between individual measures. All statistical analyses were performed using PASW software (version 18.0, SPSS, Chicago, IL). Statistical significance was set at P-values <0.05.

Image acquisition and measurement

Coronary CTA images were obtained using a 128-detector row CT scanner (Somatom Definition AS; Siemens Medical Solutions, Forchheim, Germany). CTA was performed with the following protocols: retrospective electrocardiogram gating 120 kVp, collimation 128×0.6 mm, 330-ms gantry rotation time, 160 reference mAs per rotation tube current product. CTA was achieved by injection of 70–80 ml of iodinated contrast material (400 mg iodine ml⁻¹, Imeron 100; Bracco Imaging Deutschland, Konstanz, Germany) followed by 40-ml saline flush (flow rate 5 ml s⁻¹) in the craniocaudal direction at end inspiration. Automated bolus tracking was used in a region of interest within the ascending aorta, with a signal attenuation trigger threshold of 120 Hounsfield units (HU) and a 6-s scan delay. Sublingual nitrates were given before CTA. Beta-blockers were given if the resting heart rate was >70 beats min⁻¹. CXR was performed in the upright position, and included the superior lung apex to below the costophrenic angles using the breath-hold technique with full inspiration (DigitalDiagnost; Philips Digital Radiography Solutions, Germany). The film to focus distance was 183 cm.

The vertebral body unit was defined as the distance between two adjacent vertebral bodies, including the inter-vertebral disk space, and was measured from the inferior endplate of the vertebra, at the level corresponding to the carina to the inferior endplate of the lower vertebra (Fig 2).

All images were reviewed independently and separately by two board-certified radiologists (Y.G.S. and H.J.), who have 14 and 5 years of interventional radiology experience, respectively, who were blinded to patient data. Measurements that differed by ≥3 mm were resolved by re-measurement and consensus by the two radiologists. The analysis was performed by averaging measurements obtained by the two radiologists.

Coronary CTA images were recalled from a picture archiving and communications system (PACS; Marosis-Infinitt, Seoul, Korea) to a three-dimensional workstation (Aquarius intuition; Terarecon, San Francisco, CA, USA). Data sets were viewed as interdependent multiplanar reconstructions in the original axial plane and in reconstructed coronal and sagittal planes. On multiplanar reconstructed images, the following structures were identified: the anatomic CAJ at the level corresponding to a plane through the crista terminalis and the crista dividers, the carina, and VBU at the level corresponding to the carina.

The location of the carina was determined on axial CT images that demonstrated the origins of the right and left mainstem bronchi. On CXR, the VBU was measured at the level corresponding to the carina. Using electronic calipers, the following measurements were obtained: distance from the carina to the CAJ, the VBU on coronary CTA, and the VBU on CXR. The distance from the carina to the CAJ was then measured in VBUs on both CTA and CXR.

Results

Five hundred and twenty-four patients were enrolled in this study. There were 325 male (62.0%) and 199 female (38.0%) patients. The median age at the time of examination was 59 years (range, 40–88 years), median height was 164 cm (range, 142–187 cm), median weight was 64 kg (range, 34–92 kg), and median BMI was 23.9 kg m⁻² (range, 14.4–36.6 kg m⁻²). The measured distance and the distance from the carina to the CAJ in VBUs are summarized in Table 1. The inter-rater correlation coefficients (r) for the distance from the carina to the CAJ and the height of vertebral bodies measured on CTA and CXR were 0.817, 0.832 and 0.826, respectively (P<0.001).

The correlation between the distance from the carina to the CAJ in VBUs on CTA and CXR was high (r=0.777, P<0.001) (Fig 3). The differences between measurements (CXR diameter minus CTA scan diameter) were plotted against their means (CXR diameter plus CTA scan diameter) 2⁻¹. If the differences
Study design according to the CONSORT Flow Diagram. CTA, computed tomographic angiography; VBU, vertebral body unit; CAJ, cavoatrial junction.

Fig 1 Study design according to the CONSORT Flow Diagram. CTA, computed tomographic angiography; VBU, vertebral body unit; CAJ, cavoatrial junction.

Fig 2 The carina is indicated by a single arrow. The VBU is indicated by a double-sided arrow. Anterior (A) to posterior (P), right (R) to left (L), and superior (S) to inferior (I) orientations are shown. (a) Posteroanterior (PA) chest radiography. (b) Coronary CTA multiplanar reconstructions in an adult. The vertical registration line in the axial reconstruction shows the level of sagittal reconstruction. SVC, superior vena cava; AA, ascending aorta; DA, descending aorta; RP, right pulmonary artery; LA, left atrium.

Table 1 Measured distances and distances from carinae to CAJs in VBUs. Values are means (sds) with ranges in parentheses (where applicable). Carina-CAJ, distance from carina to the cavoatrial junction; VBU(C), vertebral body unit by chest CT; VBU(S), vertebral body unit by chest radiography. Carina-CAJ VBU(C)−1, distance from carina to the cavoatrial junction in VBUs by chest CT; Carina-CAJ VBU(S)−1, distance from carina to the cavoatrial junction in VBUs by chest radiography.

<table>
<thead>
<tr>
<th></th>
<th>Carina-CAJ (mm)</th>
<th>VBU(C) (mm)</th>
<th>VBU(S) (mm)</th>
<th>Carina-CAJ VBU(C)−1</th>
<th>Carina-CAJ VBU(S)−1</th>
</tr>
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<tbody>
<tr>
<td>Total</td>
<td>54.3 (9.7)</td>
<td>21.4 (1.7)</td>
<td>22.6 (2.1)</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>(18-79)</td>
<td>(17.4-30)</td>
<td>(17.4-32.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>56.1 (9.2)</td>
<td>22.2 (1.4)</td>
<td>23.3 (2.0)</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>(35-79)</td>
<td>(17.8-30)</td>
<td>(17.6-32.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>51.4 (9.9)</td>
<td>20.0 (1.5)</td>
<td>21.6 (1.8)</td>
<td>2.6</td>
<td>2.4</td>
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<tr>
<td></td>
<td>(18-77)</td>
<td>(17.4-23.7)</td>
<td>(17.4-27.2)</td>
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between measurements are small, the plot should centre near zero (Fig. 4).

Univariate analysis showed weak but significant correlations between the distance from the carina to the CAJ in VBUs on CXR and age (r=0.251, P<0.001) and BMI (r=-0.262, P<0.001).

The distance from the carina to the CAJ in VBUs on CXR was significantly different between those aged ≥70 or <70 (P<0.001) and between those with a BMI of >25 or ≤25 (P<0.05). The distance from the carina to the CAJ in VBUs on CXR tended to be significantly greater in older patients (P<0.001) and in men. Although not significant, the distance from the carina to the CAJ in VBUs was greater for men than women in their 40–70s, while that of women was greater among those aged ≥70. Multivariate analysis was performed to correct for gender, age and/or BMI (Table 2).

The distance from the carina to the CAJ on CT was not found to be associated with height, weight, BMI, or gender. A significant but weak correlation was found between the distance from the carina to the CAJ and age in adults (r=0.183, P<0.001).

**Discussion**

CVC placement is a common procedure in clinical practice. Optimal positioning of a CVC tip is a complex issue and requires careful consideration of catheter type, insertion site, and patient habitus. Catheter misplacement can cause various complications. When the catheter is placed too high, there may be an increased risk of thrombosis, catheter malfunction, infection and SVC perforation. On the other hand, when the catheter is placed too low, there may be an increased risk of arrhythmia, pericardial placement. In the present study, when the thoracic spine was used as an internal rular, strong correlations were found between distances from the carina to the CAJ in VBUs on both CTA and CXR. Another advantage of using the VBU as a measure is that it is not an absolute measurement such as the sixth thoracic vertebra measurement, but rather uses the relative position of the CAJ from the carina, which may be more reliable in patients with different body types. The Bland-Altman plot supported this correlation, and demonstrated an underestimation of mean CAJ position below the carina on CXR. On the Bland-Altman plot, when the mean CAJ position was above 2.5 VBUs below the carina on CTA and CXR, measurements were less reliable. It appears that such imprecision reflects simple statistical variation.

Baskin and colleagues reported no statistical association between the position of the CAJ in VBUs and patient age; however, we found a weak statistical association between the two. Furthermore, the distance from the carina to the CAJ in VBUs on CXR was found to increase with age, and although not significant, a further increase in this distance was observed in women aged ≥70. For those patients in their 40, 50, and 60s, distances from the carina to the CAJ in VBUs on CXR were greater for men than women. However, the increase in the distance from the carina to the CAJ in VBUs seen between the 50s age group and those ≥70 was more prominent in women. We attribute this gender disparity to oestrogen deficiency after menopause and the rapid development of osteoporosis in women. A previous study demonstrated an age-related increase in intact PTH (a bone metabolic hormone), which was suggested to be a causative factor of bone loss in menopausal women.

In the present study, a weak but significant correlation was found between BMI and the distance from the carina to the CAJ in VBUs on CXR. We assumed that gross body habitus has an effect on CAJ position in VBUs. Therefore, we recommend that a large-scale randomized clinical trial be conducted to overcome the limitations of our study.

In an article reviewing pulmonary CTA in patients aged between 20 and 99, a distance from the carina to the CAJ of 40.3 mm (SD 13.6) was observed, and gender was not found to significantly affect the distance between the carina and CAJ. Moreover, a study on chest CT imaging in adolescents and young adults showed a distance from the carina to the CAJ of 40 mm (SD 10) and no association was found between the distance from the carina to the CAJ and height, weight, body surface area, or sex. In this previous study, CAJ position was shown to be 2.0 (SD 0.4) VBUs below the carina on chest CT. In the present study, the carina to CAJ distance was 54.3 mm (SD 0.97) or 2.5 (SD 0.5) VBUs below the carina on CTA and 2.4 (SD 0.5) VBUs below the carina on CXR. In addition, this distance was not found to be associated with patient height, weight, BMI, or gender. However, a weak but significant association was found between the distance from the carina to the CAJ and age. We believe that such differences are because of the use of different regions, sample numbers, study methods, and study groups. We found that the carina to CAJ distance increased with age and that differences were significant for patients in their 70s. In general, age-related loss of arterial compliance contributes to isolated systolic hypertension and left ventricular hypertrophy. Likewise, as lung elasticity decreases, stiffness of the chest wall increases and respiratory muscle strength declines. However, what causes the distance from the carina to the CAJ to increase with age remains to be investigated.

Many radiologic landmarks and techniques for estimating the location of the CVC tip have been investigated. However, previous studies have suggested that little normative data exist about the...
relationships between landmarks used and the CAJ. The final position of the CVC tip is usually confirmed by chest radiography. The carina has been demonstrated as a more reliable landmark and is easily visible in chest radiography. Accordingly, our study shows a more normative value for CVC placement using the carina and spine as landmarks.

Our study has some limitations. First, this study was conducted at a single institution. Second, the patient position in which the radiographs were obtained was not taken into consideration. However, previous authors have reported that the incidence of malpositioning on subsequent chest radiographs is low when central venous catheters are placed under fluoroscopic guidance in supine patients.20 21 Thus, suggesting that the amount of catheter tip migration occurring in the supine and upright positions is not clinically important.15 Third, our study population was restricted to Asians. A large-scale, multicentre study should be conducted to obtain scientific evidence in this and other populations.

Our results suggest that the position of the CVC tip can be reliably and accurately described by its relationship to the carina using the thoracic spine as an internal ruler. In particular, the present study indicates that 2.4 VBUs below the carina is a reliable estimate of the position of the CAJ in adults on chest radiography. Satisfactory outcomes can be expected if this technique is used as a radiologic guide during CVC placement.

Authors’ contributions
Study design/planning: Y.G., S.G.
Study conduct: J.H.
Data analysis: S.Y.
Writing paper: Y.G., S.G., J.H., S.Y.
Revising paper: all authors

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Declaration of interest
None declared.

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