Hong Kong J Radiol. 2022;25:277-83 | https://doi.org/10.12809/hkjr2217382

ORIGINAL ARTICLE

Achieving Optimal Central Venous Catheter Position: Evaluation of Radiographic Landmarks for Accuracy and Inter-observer Reliability in Locating the Cavoatrial Junction

KW So, HL Tsui, SM Yu, CH Suen, CW Choi, PY Chu, JCS Chan

Department of Radiology and Organ Imaging, United Christian Hospital, Hong Kong

ABSTRACT

Objective: *We sought to compare three popular radiographic landmarks for their accuracy and inter-observer reliability in determination of the cavoatrial junction (CAJ) by analysing the anteroposterior scout and electrocardiogram-gated coronary computed tomographic angiography (CTA) images.*

Methods: *CTA image data of 148 patients were assessed. The position of the CAJ defined by CTA was regarded as the gold standard. The median vertical distance between the CAJ and three radiographic landmarks (two vertebral body units [vertebrae plus discs] below the carina, the superior aspect of the right heart border, and the intersection of the bronchus intermedius with the right heart border) were assessed and compared using the Kruskal–Wallis test. For inter-observer reliability between two radiologists, each with at least 4 years of experience, intra-class correlation (ICC) was analysed.*

Results: *The median vertical distances between the CAJ and two vertebral body units below the carina, the superior aspect of the right heart border, and the intersection of the inferior wall of the bronchus intermedius with the right heart border were 5.1 mm (0-24.6), 10.2 mm (1-45.2) and 9.8 mm (0.8-45.8), respectively. The radiographic landmark of two vertebral body units below the carina provided the closest estimation of the CAJ ($p < 0.001$). It also demonstrated higher ICC (0.931, 95% confidence interval [CI]=0.905-0.950) than the other two (0.833, 95% CI=0.768-0.880 and 0.860, 95% CI=0.805-0.899, respectively).*

Conclusion: *Among the three popular radiographic landmarks for the CAJ, we found that a point two vertebral body units below the carina provided the most accurate estimate of CAJ location.*

Key Words: *Catheterization; Right atrium; Multidetector computed tomography; Radiography, thoracic; Vena Cava, Superior*

Correspondence: *Dr KW So, Department of Radiology and Organ Imaging, United Christian Hospital, Hong Kong*
Email: skw520@ha.org.hk

Submitted: 25 Apr 2021; Accepted: 27 Sep 2021.

Contributors: KWS, SMY, CHS and JCSC designed the study. KWS, CHS, CWC, PYC and JCSC acquired the data. All authors analysed the data. KWS, HLT, CHS and CWC drafted the manuscript. KWS, HLT, SMY, PYC and JCSC critically revised the manuscript for important intellectual content. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

Conflicts of Interest: As an editor of the journal, CHS was not involved in the peer review process. Other authors have disclosed no conflicts of interest.

Funding/Support: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability: All data generated or analysed during the present study are available from the corresponding author on reasonable request.

Ethics Approval: This retrospective study was approved by the Kowloon Central/Kowloon East Cluster Research Ethics Committee (Ref: KC/KE-20-0278/ER-3). Written informed consent was waived by the Committee due to the retrospective nature of the study.

中文摘要

實現最佳中心靜脈導管位置：評估放射學標誌在定位腔房交界處的準確性和觀察者間一致性

蘇建偉、徐愷靈、余燊明、孫振航、蔡雋煒、朱炳容、陳志生

目的：我們通過分析前後位探查圖像和心電門控冠狀動脈CT血管造影（CTA）圖像來比較三個常用的放射學標誌在確定腔房交界處（CAJ）的準確性和觀察者間一致性。

方法：對148例患者的CTA圖像數據進行評估。CTA定義的CAJ位置視為黃金標準。CAJ與三個放射學標誌（氣管隆突下方兩個椎體單位（椎體加椎間盤）、右心邊界的屈曲以及中間支氣管與右心邊界的交點）之間的中位垂直距離進行了評估和使用Kruskal–Wallis檢驗進行比較。對於兩位有最少4年經驗的放射科醫生之間的觀察者間一致性分析了組內相關性（ICC）值。

結果：CAJ與氣管隆突下兩個椎體單位、右心邊界上側、中間支氣管下壁與右心邊界交點的中位垂直距離分別為5.1毫米（0-24.6）、10.2毫米（1-45.2）和 9.8毫米（0.8-45.8）。氣管隆突下方兩個椎體的影像學標誌提供了最接近CAJ 的估計值（$p < 0.001$）。它有比其他兩個放射學標誌（0.833，95%置信區間=0.768-0.880和0.860，95%置信區間=0.805-0.899）更高的ICC（0.931，95%置信區間=0.905-0.950）。

結論：在CAJ的三個常用的放射學標誌中，我們發現氣管隆突下方兩個椎體單位的點提供了最準確的CAJ位置估計。

INTRODUCTION

Central venous catheter (CVC) placement, including subclavian lines and peripherally inserted central catheter lines, is a common procedure performed by interventional radiologists or clinicians for fluid management of critically ill patients or when prolonged intravenous infusion is required. The optimal position of the CVC tip remains controversial.[1] Tips located near or within the right atrium have been described to carry a risk of dysrhythmias and rarely, cardiac perforation.[2] On the other hand, tips located outside the heart are associated with venous thrombosis.[3-5]

The Association for Vascular Access, formerly known as the National Association of Vascular Access Networks, proposed a guideline in 1998 that tips should be located in ‘the lower one-third of the superior vena cava (SVC), close to the junction of the SVC and right atrium’.[6] Two other studies recommended tips should be located at the cavoatrial junction (CAJ).[4,5] Therefore, positioning of tips at the CAJ is a popular approach.

The CAJ is defined by the junction of the SVC and the true right atrium, consisting of a thickened ring of tissue formed by the crista terminalis anteriorly and the crista dividens posteriorly. These two cristae constitute the embryonic transition from the sinus venosus to the true atrium and thus form the anatomic CAJ.[7]

The cristae defining the CAJ are only visible on cross-sectional imaging such as computed tomography and magnetic resonance imaging. The CAJ cannot be directly visualised on conventional chest radiographs, which is the modality of choice to confirm tip position during and after CVC placement. Several studies have been performed to define reliable landmarks that are visible on a chest radiograph to act as a surrogate for the position of the CAJ. These studies proposed three surrogates based on visible landmarks in chest radiographs that help radiologists define the CAJ in chest radiographs: (1) two vertebral body units (inferior endplate to inferior endplate including the intervening disc) below the carina,[7] (2) the intersection of the inferior wall of the bronchus intermedius with the right heart border,[8] and (3) the superior aspect of the right heart border.[8] These studies are descriptive in nature and there is no direct comparison between these radiographic surrogates in terms of accuracy and inter-observer reliability.

The primary outcome of this study was to determinate the radiographic surrogate marker visible in the calibrated anteroposterior (AP) scout topogram which provides the best estimation of the CAJ position with reference to electrocardiographic (ECG)-gated coronary computed tomographic angiography (CTA) as a gold standard. The secondary outcome was to assess the radiographic surrogate marker carrying the best inter-observer reliability.

METHODS

Study Population

The initial study population included 188 patients (85 men and 103 women) undergoing contrast-enhanced coronary CTA at a regional hospital from 1 October 2018 to 1 October 2019. The exclusion criteria were as follows: omission of the post-contrast study due to a high calcium score as per department protocol, spinal disease (including severe lordosis or a history of spine surgery), and absence of an AP scout topogram. In total, four cases of spinal disease, four cases without an AP scout topogram, and 32 cases without contrast CTA were excluded, leaving a total of 148 cases for analysis.

Image Acquisition

Patients were referred for CTA due to symptoms of coronary artery disease. They were given 50 to 100 mg metoprolol (beta blocker) 45 to 60 minutes prior to scanning if their pulse rate was >65 beats per minute (bpm) and systolic pressure was >110 mm Hg, and they were routinely given sublingual short-acting 200 mg nitroglycerin 3 to 5 minutes prior to the scan if systolic blood pressure was >110 mm Hg.

A non-contrast AP scout image during breath holding was first acquired for localisation of anatomical structures. Non-ionic intravenous contrast material with 350 mgI/mL followed by a 50 mL saline flush was injected for the patients without a history of allergy to iodinated contrast. For patients with known allergy to iodinated contrast, following steroid cover (40 mg prednisone per dose) at 2 and 12 hours prior to scanning, iodixanol 320 mgI/mL was administered. The volume of contrast depended on the estimated scanning time, which was calculated according to patient's heart rate and the flow rate (5 mL/s). Contrast was injected through an 18G intravenous catheter in the right antecubital fossa.

A bolus triggering technique was employed to ensure optimal timing of the imaging. A region of interest was placed on the descending thoracic aorta and the monitor delay was 10 seconds. The scan was triggered with a 7-second delay when 100-Hounsfield unit (HU) increment was detected at the descending thoracic aorta. For patients with a stable heart rate <65 bpm, prospective ECG gating was employed. Retrospective ECG gating was employed if a patient's heart rate was irregular or ≥65 bpm.

Scanning extended from the level of the proximal ascending aorta to below the inferior margin of the heart including the pericardium. A 64-multidetector computed tomography scanner (SOMATOM Definition AS+; Siemens Medical System, Siemens, Erlangen, Germany) was used with the following parameters: collimation 0.625 mm × 64 = 4 cm; rotation time: 0.3 s, 140 kVp; tube current: 300 to 600 mAs; field of view: 50 cm; pitch: 0.18 to 0.24 (depending on heart rate); matrix: 512 × 512; image reconstruction: kernels (I26f); reconstruction slice thickness: 0.75 mm with 0.4-mm increments.

Image Evaluation

Images including between 68% and 72% of the R-R interval were retrieved for evaluation and were reconstructed into axial and sagittal planes. Image analysis was performed on a commercially available picture archiving and communication system workstation (Centricity Universal Viewer Version 6.0; GE Healthcare, Chicago [IL], United States). The standard CTA window settings for evaluation were window width = 500 HU and window level = 40 HU.

The axial positions in the scout images were correlated to the tube position (Figure 1). The craniocaudal positions of the CAJ and the landmarks of interest were recorded. The absolute distance between the radiographic landmarks and the CAJ determined by CTA (gold standard) were calculated.

One radiologist with 6 years' experience of radiographic and CTA imaging assessed the CTA images, without reference to the scout topogram. The CAJ was first localised on the sagittal reformatted CTA image as the midpoint of an oblique line drawn from the crista terminalis anteriorly to the crista dividens posteriorly.[8] This point was then cross-referenced with the position of the axial section image that represented the craniocaudal location of the CAJ (Figure 2).

Two radiology trainees with 4 years of experience interpreting radiographic images independently evaluated the scout topogram without knowing the

Figure 1. The craniocaudal axis (arrow) in a localising anteroposterior scout topogram was calibrated and labelled by the positions of the numbered axial section images (horizontal yellow lines) with 0.4 mm vertical distance between consecutive axial images. The craniocaudal positions of the radiographic landmarks were cross-referenced and recorded as axial slice position numbers (1-418).

position of the CAJ determined by the CTA. For each study, readers determined the location of the three interested radiographic landmarks on the AP scout topogram, including two vertebral body units below the carina (Figure 3a), the superior aspect of the right heart border (Figure 3b), and the intersection of the inferior wall of the bronchus intermedius with the right heart border (Figure 3c). The craniocaudal locations of these radiographic landmarks were recorded. If a radiographic landmark was not visible in the AP scout topogram, the position of this landmark was recorded as 'indeterminate' with reason provided.

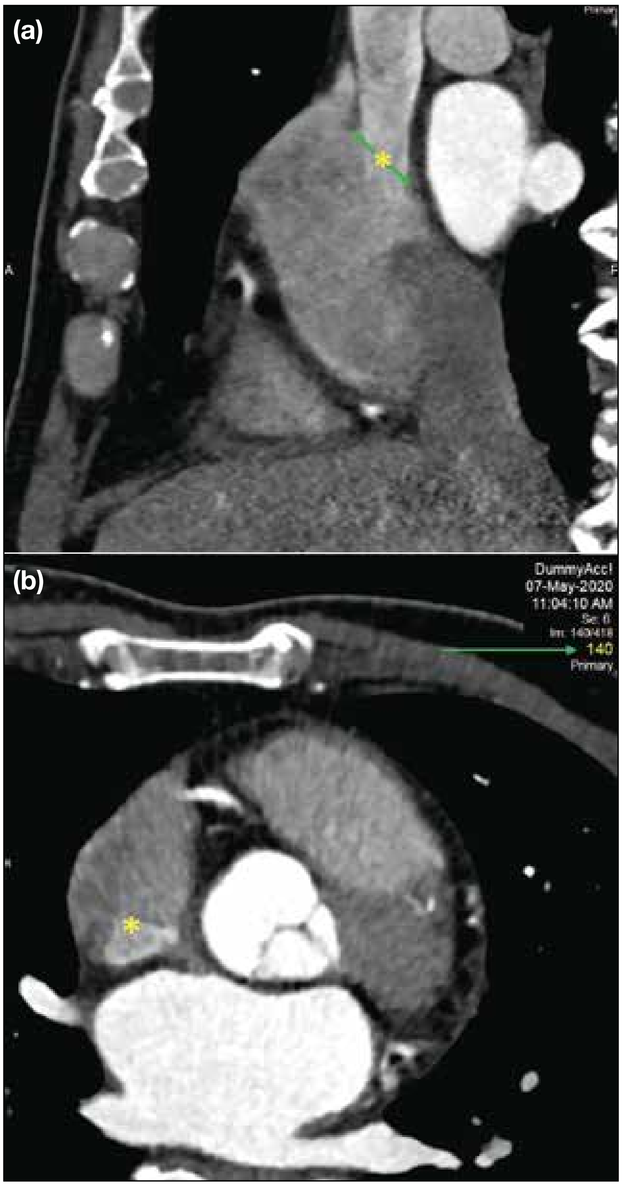

Figure 2. Example of localisation of the cavoatrial junction (CAJ) in computed tomographic angiography (CTA) images in the same patient as Figure 1. (a) The position of the CAJ was first defined in the sagittal reformatted CTA image as the midpoint (asterisk) of an oblique line (arrows) drawn from the crista terminalis anteriorly to the crista dividens posteriorly. (b) This point (asterisk) was cross-referenced to axial reformatted CTA images. The craniocaudal position of the CAJ is represented by that axial slice position number, which is number 140 (arrow) in this example. The position of the CAJ determined by CTA was the gold standard.

Statistical Analysis

All statistical analyses were performed using commercial software SPSS (Windows version 27; IBM Corp, Armonk [NY], United States). Intra-class correlation (ICC) was analysed using a two-way random effects model with emphasis on consistency for determination of inter-observer reliability so as to generalise the reliability results to any raters who possess the same characteristics as the selected raters in the reliability study.

Data were initially assessed for normality with the Shapiro–Wilk test. Based on these results, a non-parametric procedure was employed for comparison between groups as parametric test cannot be used in the present study. The vertical distances between these landmarks and the CAJ are reported as median and range.

The non-parametric Kruskal–Wallis test was used to test for overall equality of medians in each data group. The significance level (α) was adjusted by the Bonferroni correction in view of multiple comparisons, where a p value of 0.0167 (0.05/3) was considered to indicate a significant difference.

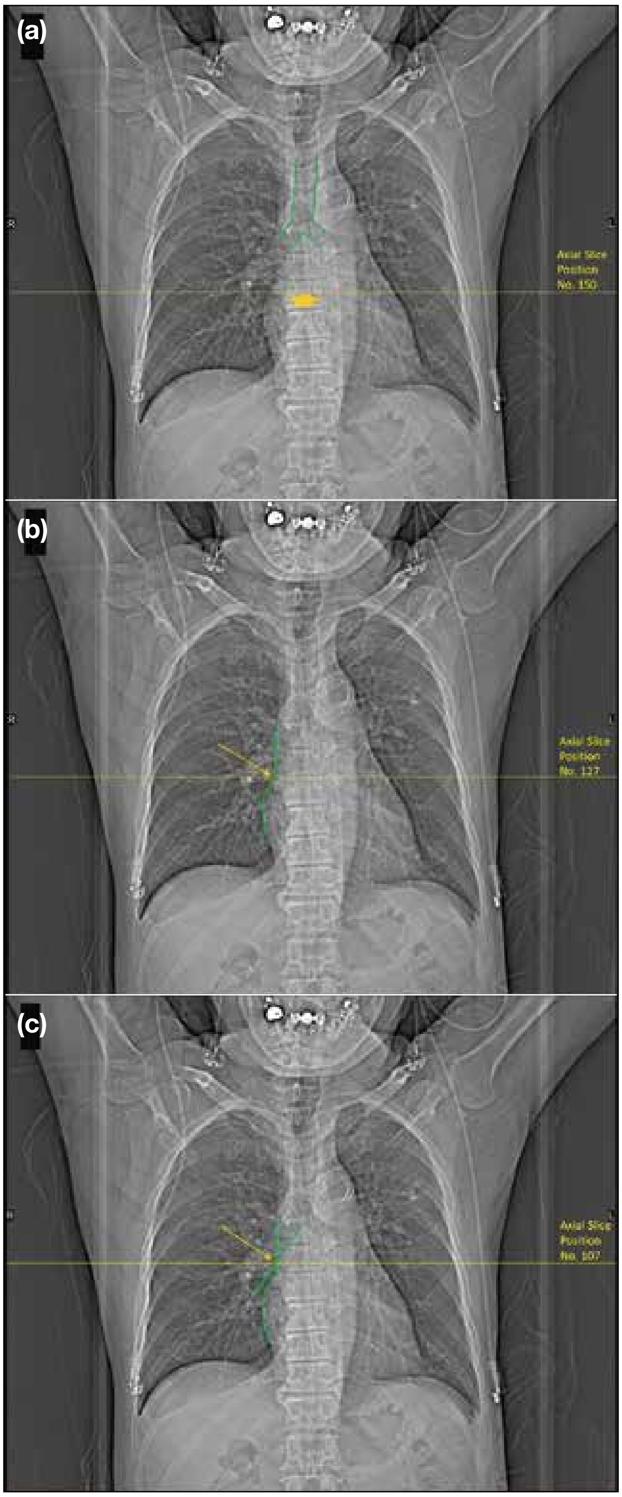

Figure 3. Examples of the radiographic landmarks for the cavoatrial junction (CAJ) and their locations in the anteroposterior (AP) scout topogram from the same patient as Figures 1 and 2. (a) The craniocaudal position of two vertebral body units below the carina (broad arrow) was cross-referenced to the corresponding axial slice position number in the calibrated AP scout topogram, which was number 150 in this example. The positions for (b) the superior aspect of the right heart border (arrow) and (c) the intersection of the inferior wall of bronchus intermedius with the right heart border (arrow) in this example were axial slice position numbers 127 and 107, respectively. The green lines in (a), (b) and (c) outline the carina, the right heart border and the right heart border and the inferior wall of bronchus intermedius, respectively.

RESULTS

Results are summarised in the Table. There were 63 male (42.6%) and 85 female (57.4%) patients. The median age at the time of examination was 62 years (range, 32-86). The radiographic landmark ‘two vertebral body units below the carina’ was visible in all 148 cases. The superior aspect of the right heart border was not visible in one case due to rotation of patient resulting in overlapping of the right heart border and the spine. The intersection of the inferior wall of the bronchus intermedius with the right heart border was not clearly visible in four patients due to rotation or branching of the bronchus intermedius proximal to the right heart border.

The vertical distances between the above landmarks and the CAJ are presented as box plots (Figure 4). The median vertical distances between the CAJ and two vertebral body units below the carina, the superior aspect of the right heart border, and the intersection of the inferior wall of the bronchus intermedius with the right heart border were 5.1 mm (range, 0-24.6), 10.2 mm (range, 1-45.2) and 9.8 mm (range, 0.8-45.8), respectively. Using the superior aspect of the right heart border as the surrogate of the CAJ yielded extreme discrepancy in two patients (39.4 and 45.2 mm), while using the intersection of the inferior wall of the bronchus intermedius with the right heart border created a discrepancy of 45.8 mm in one patient, close to the limit of 3 interquartiles. The median vertical distance between the CAJ and two vertebral body units below the carina was significantly shorter than that of the other two landmarks ($p < 0.001$) according to the Kruskal–Wallis test. There was no significant difference in the median vertical distance between the CAJ and the superior aspect of the right heart border and that between the CAJ and the intersection of the inferior wall of the bronchus intermedius with the right heart border ($p = 0.977$).

Inter-observer agreements for determination of the three radiographic landmarks were all excellent. As shown in the Table, the highest inter-observer agreement was obtained when using two vertebral body units below the carina as a radiographic landmark (ICC = 0.931, 95% confidence interval [CI] = 0.905-0.950), as compared with that of the superior aspect of the right heart border (ICC=0.833, 95% CI = 0.768-0.880) and the intersection of the inferior wall of the bronchus intermedius with the right heart border (ICC = 0.860, 95% CI = 0.805-0.899).

Table. Comparison of three radiographic landmarks: two vertebral body units below the carina, superior aspect of the right heart border, and bronchus intermedius–right heart border intersection.

Radiographic landmark	Two vertebral body units below the carina	Superior aspect of the right heart border	Bronchus intermedius–right heart border intersection
Median distance from the cavoatrial junction, mm (range)	5.1 (0-24.6)	10.2 (1-45.2)	9.8 (0.8-45.8)
Visibility (No. of cases/total cases)	100% (148/148)	99.3% (147/148)	97.3% (144/148)
Intra-class correlation (95% CI)	0.931 (0.905-0.950)	0.833 (0.768-0.880)	0.860 (0.805-0.899)

Abbreviation: CI = confidence interval.

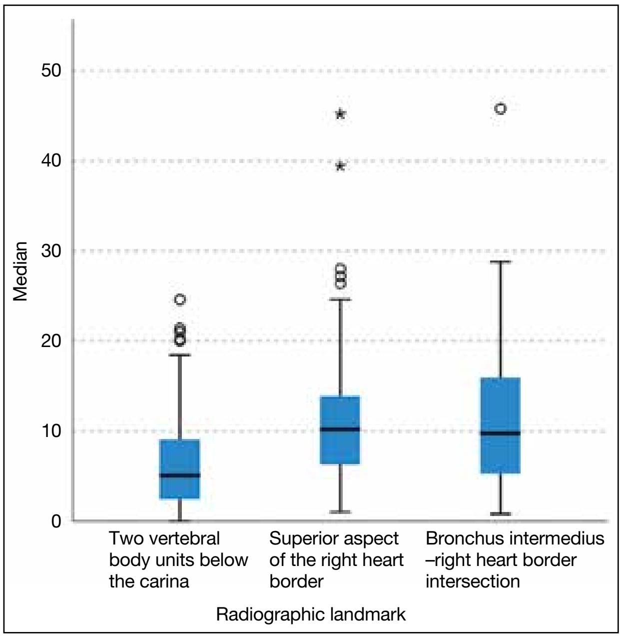

Figure 4. Box plots of vertical distances between the cavoatrial junction and different radiographic landmarks. The line within each box represents the median and the horizontal boundaries of the boxes represent the first and third quartiles. Outliers (circles) are cases with values between 1.5 and 3 times the interquartile range. Extremes (asterisks) are cases with values more than 3 times the interquartile range.

DISCUSSION

Our study attempted to define the most accurate and consistent radiographic landmark that could act as a surrogate marker for the CAJ. We have shown that the most reliable estimate of the location of the CAJ is two vertebral body units below the carina. Discrepancies between the anatomical CAJ defined by CTA and that using this surrogate marker were significantly smaller than those estimated by the other two locations. The use of two vertebral body units below the carina has also been suggested by most prior observational studies. Baskin et al[7] showed the mean vertical distance from the CAJ to the carina and to two vertebral body units below the carina were 40 ± 10 mm and 0.4 ± 8.2 mm, respectively. Similar findings were also shown by Mahlon and Yoon,[9] with the CAJ 40.3 ± 13.6 mm below the level of the carina. A study by Ridge et al[8] showed that the CAJ was 42 ± 11 mm or 2.2 vertebral body units below the carina. However, Song et al[10] found that the CAJ was 2.4 vertebral body units below the carina. We believe such differences could be due to differences in median age and exclusion of lung diseases in their study. In our study, we do not exclude patients with lung disease in order to improve generalisability of our results as patients with lung diseases may also need placement of CVC. A study by Aslamy et al[11] shows that the superior aspect of the right heart border in magnetic resonance imaging usually represents the superimposition of several mediastinal structures, such as the hilar vessels or even the right epicardial margin of the left atrium, indicating it does not solely represent the CAJ. In another study by Baskin et al,[7] the superior aspect of the right heart border usually represents the point at which the SVC descends posterior to the right atrial appendage. Such findings could explain the larger discrepancies between the anatomical CAJ and using the superior aspect of the right heart border on chest radiographs in predicting the actual location of the CAJ as shown in our study. The intersection of the inferior wall of the bronchus intermedius with the right heart border was the least frequently visible (97.2%) landmark on scout topogram in our study. This landmark was reported to be visible on 71% of scout topograms in a study by Ridge et al,[8] indicating that this landmark can be affected by rotation of the patient, lung volume and heart size, limiting its accuracy and inter-observer reliability.

The use of the spine as an internal reference has several advantages. The spine is only minimally affected by geometric magnification and is adaptive to somatic growth, which will aid in accurate catheter placement.[7] The spinal structures and the carina are easily identified on chest radiographs, which may translate into better inter-observer reliability. Our study showed the inter-observer reliability for determination of two vertebral body units in radiographs is higher than that of the other two radiographic surrogates without overlap between the 95% CI of the ICCs. It is also worth mentioning that CVC tips can migrate up to 2 cm cephalad to their original position when a patient moves from the supine to the erect position.[12] Tips may also migrate up to 2 cm caudad to their original position if patients abduct their arms.[13] The effects of patients' body and arm positioning on the catheter tip position should be considered when assessing follow-up chest radiographs to prevent overcalling of tip migration. In an ideal situation, standardisation of patient positioning for chest radiographs intended for follow-up assessment of catheter tip position should be employed.

This study has a few limitations. First, this study was conducted in a single institution and was restricted to South East Asians. In order to generalise our findings to other populations, a multicentre large-scale study should be conducted. Second, patients' arms were in the abducted position when CTA and AP scout topograms were taken, which is usually not the position during CVC placement. The resolution of a scout topogram is inferior to conventional chest radiographs. This may have impact on the inter-observer reliability on determination of the radiographic landmarks. However, we believe the image quality of scout topograms simulates the real-life situation during CVC placement under fluoroscopic guidance where the image resolution is similar.

CONCLUSION

Positioning of a CVC tip at the CAJ has been recommended by many studies to avoid potentially fatal catheter-related complications such as dysrhythmia, cardiac perforation, and venous thrombosis. Several radiographic landmarks have been proposed to describe the location of the CAJ in chest radiographs. Our study demonstrated two vertebral body units below the carina provided the most accurate estimation of CAJ position and had the best inter-observer reliability among these radiographic landmarks.

REFERENCES

1. Vesely TM. Central venous catheter tip position: a continuing controversy. J Vasc Interv Radiol. 2003;14:527-34.
2. Pittiruti M, Lamperti M. Late cardiac tamponade in adults secondary to tip position in the right atrium: an urban legend? A systematic review of the literature. J Cardiothorac Vasc Anesth. 2015;29:491-5.
3. Luciani A, Clement O, Halimi P, Goudot D, Portier F, Bassot V, et al. Catheter-related upper extremity deep venous thrombosis in cancer patients: a prospective study based on Doppler US. Radiology. 2001;220:655-60.
4. Amerasekera SS, Jones CM, Patel R, Cleasby MJ. Imaging of the complications of peripherally inserted central venous catheters. Clin Radiol. 2009;64:832-40.
5. Vesely TM, Beathard G, Ash S, Hoggard J, Schon D, ASDIN Clinical Practice Committee. A position statement from the American Society of Diagnostic and Interventional Nephrology. Semin Dial. 2007;20:359-64.
6. Tip location of peripherally inserted central catheters [editorial]. J Vasc Access Devices. 1998;3:8-10.
7. Baskin KM, Jimenez RM, Cahill AM, Jawad AF, Towbin RB. Cavoatrial junction and central venous anatomy: implications for central venous access tip position. J Vasc Interv Radiol. 2008;19:359-65.
8. Ridge CA, Litmanovich D, Molinari F, Bankier AA, Eisenberg RL. Radiographic evaluation of central venous catheter position: anatomic correlation using gated coronary computed tomographic angiography. J Thorac Imaging. 2013;28:129-33.
9. Mahlon MA, Yoon HC. CT angiography of the superior vena cava: normative values and implications for central venous catheter position. J Vasc Interv Radiol. 2007;18:1106-10.
10. Song YG, Byun JH, Hwang SY, Kim CW, Shim SG. Use of vertebral body units to locate the cavoatrial junction for optimum central venous catheter tip positioning. Br J Anaesth. 2015;115:252-7.
11. Aslamy Z, Dewald CL, Heffner JE. MRI of central venous anatomy: implications for central venous catheter insertion. Chest. 1998;114:820-6.
12. Schutz JC, Patel AA, Clark TW, Solomon JA, Freiman DB, Tuite CM, et al. Relationship between chest port catheter tip position and port malfunction after interventional radiologic placement. J Vasc Interv Radiol. 2004;15:581-7.
13. Forauer AR, Alonzo M. Change in peripherally inserted central catheter tip position with abduction and adduction of the upper extremity. J Vasc Interv Radiol. 2000;11:1315-8.