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Topographic analysis and evaluation of anatomical landmarks for placement of central venous catheters based on conventional chest X-ray and computed tomography

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Editor's key points

- Placement of central venous catheters (CVCs) outwith the pericardial sac is important to minimize complications.
- This retrospective analysis compared computed tomography and chest X-ray for anatomical landmarks in CVC placement.
- Considerable variation was found in the extrapericardial length and position of the superior vena cava.
- CXR is not a reliable way to confirm extrapericardial placement of a CVC.
- Further studies are needed to assess the reliability of the proposed measures for CVC placement.

Background. Positioning central venous catheters (CVCs) in the proper part of the superior vena cava (SVC) is difficult. The aim of this exploratory study was to analyse topographic relationships of the extrapericardial SVC using chest X-ray (CXR) and computed tomography (CT). This included an appraisal of rules for optimal CVC tip placement.

Methods. We retrospectively evaluated 100 patients with CVCs who underwent bedside CXR and CT on the same day. Distances between the sternoclavicular joint (SCJ), tracheal carina, SVC origin, pericardial reflection, and CVC tip were analysed on CT and, if visible, on CXR. These measurements served to locate the extrapericardial SVC in relation to anatomical landmarks. Different strategies for CVC tip positioning were evaluated.

Results. The mean (standard deviation) extrapericardial length of the SVC was 26 (12) mm. The average position of the pericardial reflection was 5 mm below the carina (range, 29 mm below to 25 mm above). In our patient population, the best results in terms of tip positions in the extrapericardial SVC would have been achieved by using 85% of the SCJ-to-carina distance (in 86%) or by positioning the CVC tip 9 mm above the carina (in 84% of patients).

Conclusions. The extrapericardial part of the SVC varies considerably in length and position, and rules of thumb based on anatomical landmarks should be used cautiously. In our series, using 85% of the SCJ-to-carina distance or placing the CVC tip 9 mm above the carina would have resulted in a high percentage of positions in the extrapericardial SVC.

Keywords: central venous catheter; chest; computed tomography; sternoclavicular joint; X-ray

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Central venous catheters (CVCs) are invaluable in intensive care, and CVC placement is one of the most frequent vascular interventions performed in intensive care units.[1]

If the tip of the catheter is inadvertently placed inside the pericardial sac, this may cause life-threatening complications such as pericardial tamponade secondary to vessel wall erosion.[2–4] Pericardial tamponade is a rare complication with a reported incidence of up to 1.4% and mortality rates of 47–100%.[3 5] To avoid this severe complication, it is recommended to place the CVC tip within the superior vena cava (SVC) above the pericardial reflection—the duplication of the pericardium at the upper end of the pericardial sac—outside the heart, ideally in the extrapericardial part of the SVC.[6]

Although correct catheter placement is commonly checked by portable chest X-ray (CXR),[7] neither the pericardium itself nor the pericardial reflection can be identified by projection radiography. Therefore, various studies have been undertaken to elucidate the relationship between the pericardial reflection and anatomical landmarks detectable with projection radiography. These cadaveric studies may not accurately represent the *in vivo* situation due to tissue shrinkage.[8 9] Up to now, the carina and the right tracheobronchial angle have been considered the most suitable landmarks for catheter placement.[8–14] In clinical practice, the carina is commonly used for anatomy-based catheter positioning.[15] In addition, the clavicular notch, as a palpable anatomical landmark of the sternoclavicular joint (SCJ), may also be helpful for CVC placement. In previous studies, it has been used to define the confluence of the internal jugular vein and the subclavian vein.[11]

The aim of the present study was to conduct an exploratory analysis of topographic relationships of the extrapericardial SVC, tracheal carina, and SCJ using CXR and computed tomography (CT) (standard of reference). Using these anatomical

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landmarks, we applied and compared different rules for CVC tip placement on CXR and CT.

Methods

Patients and sample size

Our retrospective study was approved by the responsible ethics committee (application No. EA1/278/11), and a waiver for informed consent was granted. All CT and CXR examinations were performed for clinical indications. Patients over 18 with CVCs in place who had undergone CXR and CT on the same day were identified by a database search. Patients with chest wall deformities were excluded.

The study was designed as an exploratory analysis with the extrapericardial length of the SVC as the primary target variable. Based on published data, we assumed a mean [standard deviation (SD)] extrapericardial length of the SVC of 30 (15) mm.[9 16] A 95% confidence interval (CI) of $\pm$3 mm (i.e. 27–33 mm) was aimed at since this length is considered to be accurately measurable on vascular CT and resulted in a sample size of 100.[17]

Imaging

Bedside chest radiographs were obtained using standard portable equipment (Mobilett XP Eco, Siemens Medical Systems, Forchheim, Germany) and storage phosphor plates (Kodak PQ Elite CR direct view, Carestream Health Inc., Rochester, NY, USA) with the following parameters: tube current, 100 kV; tube–film distance, 1.2 m; and exposure time product, 0.6–1.25 mAs. All CXRs were performed in the anterior–posterior projection with the patient's arms besides the chest.

Chest CT was performed after i.v. administration of iodinated contrast medium (Iobitridol 350, Guerbet, Sulzbach, Germany, or Ultravist 370, Bayer, Leverkusen, Germany) with vessel contrast varying according to the clinical questions to be answered. All examinations were performed on routine clinical CT scanners (Definition and Somatom 16 slice, Siemens Medical Systems, Forchheim, Germany). A tube current of 120 kV and rotation time of 0.5 s was used. Slice thickness varied between 0.75 and 2 mm, depending on the clinical protocol used. For the CT scans, arms were usually placed above the head, except for trauma scans.

Data evaluation and measurements

Images were evaluated on a standard clinical picture archiving and communication system workstation (Centricity RIS 104i, General Electric Healthcare, Barrington, IL, USA). The readers of CT and CXR images were blinded to patient name and imaging date.

On CXR, the standard software instrument measured the distances of the catheter tip to the carina and to the upper margin of the right SCJ (example shown in Fig. 1).

On CT, distances between the tip of the CVC and the pericardium and also the carina and the right SCJ were calculated using the table positions on axial images (example shown in Fig. 1).

Statistical analysis

Means and SD were used for describing the distribution of the landmark measurements. CIs were calculated using normal approximation, as no relevant deviation from normal distribution was detected when checking Q–Q plots and histograms. The agreement of distances between CT and CXR was analysed using the Bland–Altman plots and 95% limits of agreement (95% LoA).[18] The association of between-method differences and mean differences in the Bland–Altman plots was analysed using Pearson's correlation coefficient (r). Statistical analysis was performed using SPSS for Windows (version 20.0) and R (version 2.15.3, R Foundation for Statistical Computing, www.R-project.org).

Optimization of tip position using landmarks

We used the individual patient measurements to assess three different strategies for CVC placement within the extrapericardial SVC while avoiding intrapericardial placement.

- Fixed distance to the upper margin of the right SCJ.
- Fixed distance to the carina in CXR and CT.
- Percentage of the SCJ-to-carina distance in CXR and CT.

Results

The 100 patients included in the analysis (64 men, 36 women) had a mean age of 53 yr (range, 18–80 yr). All images were interpretable and none of the examinations had to be excluded due to non-visibility of the tip of the CVC or the anatomical landmarks.

Anatomical presentation in CT

The target segment for CVC placement—the extrapericardial SVC—had a mean length of 26 (12) mm and ranged from 1 to 52 mm. In 10% of patients, the length of the extrapericardial SVC was $<$9 mm and in 30% $<$20 mm. The mean intrapericardial length was 38 (12) mm, ranging from 18 to 86 mm. On average, the pericardial reflection was 5 (10) mm below the carina. In 31% of all patients of our series, the pericardial reflection was located above the carina with a maximum of 25 mm. In 92% of all patients, the pericardium extended no more than 10 mm above the carina.

The mean distance from the SCJ to the pericardial reflection was 78 (18) mm with the smallest distance measuring at 43 mm. The mean distance from the SCJ to the origin of SVC was 53 (14) mm, ranging from 13 to 93 mm. The data are summarized in Table 1.

In our series, CVC tips were placed intrapericardially in 48%, in the extrapericardial SVC in 34%, and above the confluence of the SVC in 18% of cases.

Agreement of distances between CT and CXR

CT and CXR measurements are outlined in Table 2. The Bland–Altman plots showing the agreement between distances measured in CT and CXR are presented in Figure 2. The mean difference in the SCJ-to-carina distance between CT and CXR