Optimized method for correct left-sided central venous catheter placement under electrocardiographic guidance

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Editor’s key points

- ECG guidance can be used for central venous catheter (CVC) placement.
- Seldinger’s wire, used for transducing ECG, led to consistent error in placing a left-sided catheter.
- The error could be corrected by further advancing the catheter by 10–20 mm.
- This paper describes improvement on currently practised ECG-guided placement of CVCs.

Background. Central venous catheter (CVC) placement under ECG guidance in the left thoracicervical area can lead to catheter misplacement. The aim of this study was to identify the cause and quantify the magnitude of this error.

Methods. CVCs were sited in either the left or right internal jugular (IJ), subclavian (SC), or innominate (brachiocephalic) vein using the Seldinger technique and a total of 227 insertions were studied. The position of the catheter tip was confirmed with two different intra-atrial ECG monitoring methods (Seldinger’s wire vs 10% saline solution). Measurements were compared between the two methods and correlated to the different access sites.

Results. All right-sided CVC had the line tip in the optimal position and both intra-atrial ECG recording by Seldinger’s wire or 10% saline delivered correct results. For left-sided lines, however, the two methods gave significantly different results regarding the position of the line tip for each insertion site. When using the Seldinger wire as intravascular ECG lead, the results differed from the saline method by a mean of 21 mm for the IJ and 10 mm for the SC.

Conclusions. CVC placement under ECG guidance is a reliable method to site the line tip at the optimal position. However, when using a left-sided thoracocervical access point, the Seldinger wire-conducted ECG delivered a constant error. This could be adjusted for by advancing the ECC 20 mm in addition to the wire-based measurement of the insertion depth at the left IJ vein and 10 mm at the left SC vein.

Keywords: central venous catheters; complications, catheter misplacement; intra-atrial ECG; measurement techniques; veins, internal jugular; subclavian; brachiocephalic

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There is significant morbidity and mortality associated with complications secondary to central venous catheter (CVC) misplacement.¹ Left-sided thoracocervical central lines are particularly prone to problems, despite accepted procedures to confirm the line position.² In Germany, CVC placement under ECG guidance to verify the position of the line tip is now used almost universally.³ Despite the good validity of this method, when using the Seldinger wire to transduce the ECG signal during left-sided CVC insertions, catheter misplacements may still occur. Frequently, the CVC tip is too far proximal in the superior vena cava (SVC) in spite of an apparently accurate ECG trace and insertion procedure. This results in an unfavourable angle between the vessel wall and catheter (>40°) which is associated with vessel perforation, catheter-related infection, and malfunction.⁴ Consequently, previous studies have concluded that CVC placement under ECG guidance in its traditional interpretation (by retracting the CVC until P-wave normal) is unsuitable for left-sided thoracocervical central lines.⁵

However, conventional ways to assess the position of CVC such as chest X-rays or clinical methods remain inferior to an ECG-based approach. Gold standard methods such as transoesophageal echocardiography (TOE) are invasive and not readily available.

As a result, CVC placement under ECG guidance remains widely accepted in Germany as the method of choice for ensuring correct placement. There remains uncertainty as to whether the two commonly used methods to obtain the ECG trace behave similarly or whether one approach is superior. The techniques used are based on an ECG trace being obtained through a Seldinger wire or a saline solution-locked CVC lumen to measure the catheter tip position.⁶

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The aims of our research were two-fold, first to establish whether there was a discrepancy between the two methods of ECG transduction and relate this to the tip position and secondly to identify possible factors that may underlay any potential differences. All the established thoracocervical puncture sites were included in this study, that is, internal jugular (IJ), subclavian (SC), and innominate (brachiocephalic) vein.

We hypothesize that the measurement error when using the Seldinger wire for the intra-atrial ECG only occurs in left-sided CVC and is different in magnitude depending on the access point.

**Methods**

This prospective single-centre study was performed in the Department of Anaesthesiology and Intensive Care Medicine between March 2006 and April 2008. The local ethics committee approved the study protocol.

To increase the clinical relevance, the study included patients receiving ventilatory support [long-term ventilation at the intensive care unit (ICU; 53.1%), CVC insertion as part of the preoperative management after induction of anaesthesia (32.7%), tracheal intubation in the emergency admission unit with subsequent CVC placement (9.2%) and patients with spontaneous respiration (5%)].

In total, 260 patients were enrolled in the study, of which 10 had two CVC insertions performed. One hundred and eleven patients (42.7%) were female and 149 (57.3%) were male. Baseline patient characteristics of the study population are summarized in Table 1.

In general, we aimed to achieve a balanced use of the different venous access points.

Even though the decision about the CVC insertion site was always taken on clinical grounds, if all large central veins were available, the aim to have a similar number of access procedures for each site would have influenced the final choice in a non-randomized fashion. Most of the time, however, clinical necessity (change of site when changing catheter, SC vein preferred access point in the ICU, unsuccessful venous puncture attempts, and predefined venous access points for certain clinical or surgical settings) or anatomical circumstances (thrombosed vein, pneumothorax, damaged vessels, anatomical anomalies, and body habitus) dictated which side and vein were chosen. Nevertheless, the distribution of access points in this study was balanced between the central veins on both sides, albeit there was a slight preference for the SC vein (Fig. 1).

Interoperator variability was eliminated as all catheters were inserted by the same anaesthetist following a standardized sequence of steps using anatomical landmarks and a sterile Seldinger technique. Two-dimensional imaging ultrasound guidance was only used in difficult cases and not real time. A detailed account of the insertion technique can be found in the Supplementary Appendix.

After insertion of each catheter, the correct position and depth of insertion were estimated by two different ECG-based methods using the Certodyn® universal adaptor (Fa. B. Braun Melsungen AG, Germany). The first measurement used the Seldinger wire as intra-atrial ECG lead. For the second, the guide wire was removed and replaced by a 10% saline lock as a conducting medium using the Alphacard-System® (B. Braun Melsungen AG). The line tip was placed at the point of maximum P-wave amplitude for each measurement and the depth measured. At this position, the line tip lies in close proximity to the crista terminalis, at the junction between the SVC and right atrium.7 8 The saline-based reading was considered to be optimal and the line secured.

In 23 CVC insertions (8.5%), TOE was performed for diagnostic indications. In these cases, it was possible to assess the catheter tip position sonographically. Providing the catheter tip was within 0.5 cm above or below the base of the crista terminalis, the position was considered to be accurate.9 10

If the patient had a diagnostic chest X-ray (anterior–posterior, patient recumbent) within 24 h after line insertion, it was also used to assess the CVC position.

Forty-three X-rays were unavailable for analysis as the image had not been digitalized or could not be evaluated for other reasons. The line tip was considered to be in the correct position if placed within 55 mm below the carina.10 In addition, the angle between the CVC tip and vessel wall was measured and regarded as correct if <30° (Fig. 2).

**Statistics**

All data were analysed using SAS® software version 9.1 (SAS Institute Inc., Cary, NC, USA, 2003). The differences in the results between the two methods were compared using the χ² test. The absolute values were compared applying the SAS MIXED procedure (F-test). Patient characteristic data were grouped according to venous access sites and gender and comparisons between groups made using the Wilcoxon rank-sum test. A value of P<0.05 was considered statistically significant.

**Results**

Distribution of the baseline patient characteristics including age, height, weight, gender (except for the right innominate vein), and BMI was similar across all venous access sites.

Table 1 Patient characteristics

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<tr>
<td>Age (yr)</td>
<td>61.5 (14.6)</td>
<td>13</td>
<td>82</td>
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<tr>
<td>Height (cm)</td>
<td>171.5 (8.6)</td>
<td>140</td>
<td>196</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.0 (17.8)</td>
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<tr>
<td>BMI</td>
<td>26.8 (5.4)</td>
<td>16.1</td>
<td>52.4</td>
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On the basis of the principle that the point of maximum P-wave amplitude marks the optimal position of the CVC line tip, it was possible to place all 270 central lines in this study at the correct position.

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**Table 1**

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In 11 of the 270 CVC insertions, it was not possible to advance the Seldinger wire at the first venous puncture and a second puncture had to be performed. In 12 of the 270 cases, the CVC tip was in a central vessel other than the SVC (Supplementary Appendix Table S1), and had to be re-sited. One catheter was placed extravascularly and one arterially, both in spite of reassuring ECG-based measurements. These lines entered into the analysis after correcting the misplacements.

For each catheter, the correct position of the line tip was confirmed on a chest X-ray taken after the procedure. All catheter tips were located within 55 mm below the carina and every angle between the CVC tip and vessel wall was <30°. There was no radiological evidence of any complications. Of the 270 central venous catheterizations, 227 were included in the statistical analysis. Forty-three cases were excluded on the basis of no available chest X-ray. Each venous access point was analysed, but the number of CVC introduced via the innominate veins was too small for a statistically meaningful result.

For right-sided IJ and SC insertions, the measured depth of insertion did not differ significantly between the two methods. On the left side, however, the measured depth was significantly different between the two methods of measurement and between IJ and SC insertion sites. Entering the left IJ vein, the mean depth of insertion measured through 10% saline was 22.8 (standard deviation (SD) 1.80) cm and through the wire 20.7 (1.74) cm. For the left SC vein, the results were 22.3 (1.96) and 21.3 (1.98) cm, respectively. The mean difference at the left IJ vein was 21 and 10 mm at the left SC vein, both statistically significant. Analysis of the measurements for the innominate veins showed a similar trend, but the number of catheters was too small for a meaningful statistical analysis. The overall mean difference between the two ECG methods on the left side was 16 mm. Table 2 summarizes data from all six entry sites used in this study.

Twenty-three patients had a TOE performed after the CVC insertion. In all these cases, the line tip was found to be placed correctly within 0.5 cm of the basis of the crista terminalis, the echocardiographic equivalent to the junction between the SVC and right atrium.11 12

Discussion

Our work confirms results from a previous study, which had shown that both ECG-guided CVC insertion methods reliably lead to accurately placed right-sided IJ line tips but in left-sided IJ lines can give measurement errors when transducing through the wire.13 It also verifies our hypothesis that when using the Seldinger wire for the ECG confirmation of the CVC tip placement, a measurement error occurs only on the left side and the magnitude varies depending on the insertion site. This study extends the findings of previous research by showing that transduction of the ECG signal through the Seldinger wire in left thoracocervical central lines results in a CVC tip that by ECG criteria lies too far proximal in the SVC, irrespective of the point of insertion. This over-estimation
of the correct tip position was not evident using any of the right-sided approaches.

A number of factors should be considered to explain these differences. At first, the methods themselves should be critically analysed to identify whether the actual method or problems during the measurement procedure can explain the measurement error when using the wire to conduct the intra-atrial ECG on the left side. In addition, it needs to be clarified whether there are alternatives to the intra-atrial ECG-based confirmation of the CVC tip position.

It has been shown that the ideal position for the catheter tip is at the junction of the SVC and right atrium—the crista terminalis—and when sited at this point, the magnitude of the P-wave is maximal. These prospective, randomized, controlled studies validated the ECG-based method for CVC placement at the IJ veins by using TOE to assess the correct line tip position. They also assessed the safety profile of this method. The potential risk of pericardial tamponade through vessel wall perforation below the pericardial reflection was discussed, since the ECG-based method leads to the CVC tip being placed below the reflection. It was concluded that the line tip at the crista terminalis and the resulting parallel position to the vessel wall are safer than retracting the catheter tip to a position presumed to be above the pericardial reflection. The exact anatomical height of the reflection can be quite variable which makes it an unreliable landmark in individual cases. In addition, the line tip might be above the reflection, but the angle between the tip and vessel wall is then often more perpendicular, thereby increasing the risk of perforation and malfunction.

The method to correctly place CVC tips under ECG monitoring utilizes measurable electrophysiological phenomena occurring during emergence and conduction of the electrical impulse that initiates contraction of the heart. The physiological processes underlying the measurable electrical signals and also the physical mechanisms determining the amplitude of the signal are well understood and documented elsewhere.

The anatomical position correlating with the maximum P-wave amplitude has been confirmed in a number of studies. These prove that it is located within the area of the main right atrial conduction pathways along the crista terminalis and anterior limbus of the fossa ovalis.

For the intra-atrial ECG, the signal conducted via the CVC, both through the Seldinger wire or a CVC lumen filled with 10% saline, is dependent on the same electrophysiological phenomena, and therefore, this is unlikely to explain the different results for the two methods. Because of the very good electrical conducting characteristics of blood, the slight protrusion of the Seldinger wire from the catheter tip does not influence the measurements (Supplementary Appendix Fig. S2).

It is striking that on both sides, the catheter tip sited in the optimal position when the ECG trace was conducted via the saline filled CVC lumen. In contrast, when using the Seldinger wire, there were differences compared with the saline method on the left side of up to 30 mm. Using the wire method on the left side of up to 30 mm above the crista terminalis. It may still, however, be within the 55 mm tolerance using X-ray criteria.

The fundamental difference between the saline and wire method is that the latter gives the CVC additional stiffness. This leads to a slightly different position of the CVC within the left central veins when taking the ECG reading. Our data also suggest that this error is further exacerbated when accessing the central veins via the left IJ vein when compared with the left SC vein. The central venous anatomy on the left side is characterized by one (SC vein) or two (IJ vein) almost rectangular venous confluences, whereas on the right side, the angle of these confluences is much more obtuse.

The combination of increased CVC stiffness because of the Seldinger wire and the number of almost rectangular venous confluences to be traversed are unique to the left central venous anatomy. After confirming the CVC tip position, the Seldinger wire is removed with a consequent loss of rigidity

<table>
<thead>
<tr>
<th>Method</th>
<th>Side</th>
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<th>Mean</th>
<th>Standard deviation</th>
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<td>1.80</td>
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Table 2: Depth of insertion (cm) using the Seldinger wire or saline methods at different sites for central venous cannulation.
and a presumed change of catheter course within the central veins. The question remains whether there are better methods, given that in Germany, ECG-guided CVC tip positioning has been almost universally adopted. Direct visualization of important anatomical structures would undoubtedly be superior. TOE and cross-sectional imaging (computed tomography or magnetic resonance imaging) are valid imaging modalities to be considered. However, for routine use, both are unsuitable as they are associated with enormous technical and staffing requirements and increased financial burden.

Estimation of the required depth of CVC insertion based on the body height is inaccurate. Even though our and other investigators’ data show a linear relationship between the body height and depth of insertion, when looking at individual values, it becomes apparent that this method is too imprecise. For example, in our own study population, the estimated required depth of insertion for a body height of 180 cm when inserting via the left SC vein varies from 18 to 26 cm, which is incompatible with a sensible approximation of the insertion depth (Supplementary Appendix Fig. S2). The same applies to the more clinical methods such as free aspiration of all CVC lumina and breath synchronous movement of the blood column.

The standard anterior–posterior chest X-ray post-insertion and real-time X-ray imaging are the most commonly applied control methods to confirm the CVC tip position. The available evidence suggests that in isolation, these approaches lack validity, as only the CVC tip but not the important anatomical structures are visualized. Even the use of i.v. contrast agents would not solve this problem. The ECG-guided method may be superior to X-ray localization as only the former enables the reliable placement of the CVC tip at the base of the crista terminalis at the junction between the SVC and right atrium.

This also highlights a weakness of our study, which used a chest X-ray taken after the line insertion to confirm the CVC position. A TOE is the gold standard to confirm the exact CVC position; however, this was not performed routinely in our study. Only in 10% of the cases was a TOE available to directly confirm the CVC position.

Undoubtedly, there will be occasions when a chest X-ray after line insertion is necessary to exclude complications and misplacements and assess the angle between the vessel wall and line tip. This holds particularly true if there is no change in P-wave morphology, as seen in 12 cases in our study, as this is a strong indicator of catheter misplacement. It also applies to circumstances where the ECG-guided method cannot be used or gives equivocal results. Clear radiological criteria to relatively accurately assess the catheter tip position are available.

It should be mentioned that the phenomenon of P-wave morphology change can also be observed with CVC placed in an arterial vessel or extravascular as long as the catheter tip is in proximity to the crista terminalis. Previous studies have looked at this problem. Clinical signs should alert the operator and X-ray imaging will help to identify the misplacement.

Our study confirms that the ECG-guided CVC placement is an accurate and valid tool to place the CVC tip at the optimal anatomical location. On the left side, the ECG conduction via the Seldinger wire leads to a measurement error. Because this error is almost constant, it could be included as a constant variable in the insertion process and thereby eliminated.

In summary, a right side central vein should be the preferred port of entry if available, since with either saline or wire-based ECG-guided method, the CVC tip could always be placed in the optimal position. If a left-sided central vein needs to be accessed, the ECG-guided method gives reliable results too, providing that the wire-associated measurement error is corrected. Since this error is constant for each access site, it can be adjusted for within the insertion procedure. We have now moved in our hospital towards advancing the CVC 20 mm in addition to the wire-based measurement of the insertion depth at the left IJ vein and 10 mm at the left SC vein with good results. Equally, applying the saline-based method will give correct results at only a small additional equipment cost. For this method, the CVC tip should be sited at the point of maximum P-wave amplitude using the wire technique, then pulled back until the P-wave normalizes, and re-advanced under saline-based ECG guidance.

Supplementary material
Supplementary material is available at British Journal of Anaesthesia online.

Conflict of interest
K.R. received speakers’ fees and an unrestricted grant for the VISEP (Efficacy of Volume Substitution and Insulin Therapy in Severe Sepsis) study from B.Braun Melsungen AG (Melsungen, Germany). W.S. has served as consultant and speaker for B.Braun Melsungen AG (Melsungen, Germany). All other authors declare that they have no competing interests relevant to this manuscript.

References


