Central Venous Catheter Tips Showing Pigtail Features on Chest X-Ray to Both Sides of the Sternum-Highlighting the Causes

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Abstract

Despite the level of skill of the operator and the use of ultrasound guidance, central venous catheter (CVC) placement can result in CVC malpositioning, i.e., an unintended placement of the catheter tip in an inadequate vessel. CVC malpositioning is not a complication of central line insertion; however, undiagnosed CVC malpositioning can be associated with significant morbidity and mortality.

INTRODUCTION

Central venous catheters (CVCs) are designed to access the central venous circulation and are normally inserted via the Seldinger guide wire technique. CVCs are an essential component of modern-day critical care and emergency medicine. In this context, CVCs are used to administer life-supporting fluids, potentially irritant drugs, blood products, and parenteral nutrition. In other settings, CVCs are used to provide access for hemodialysis, transvenous heart pacing, and monitoring of hemodynamics by measuring central filling pressure and cardiac output [1,2]. But the insertion of central venous catheters is not free of complications, even when performed by skilled professionals [3].

The most common adverse events associated with CVC insertion, extensively addressed in the literature, include mid- and long-term infection (5% to 26%), thrombosis (2% to 26%), and mechanical complications during the central venous access procedure (5% to 19%), with a nearly 7% malpositioning rate among skilled operators [1,3]. However, mechanical complications related to the access procedure are expected to be significantly reduced by the practices of ultrasound guidance and ultrasound assistance [4,5].

A less commonly described yet important complication of CVC placement is malpositioning of the CVC tip in a vessel other than the SVC increases the risk of catheter wedging, erosion or perforation of vessel walls, local venous thrombosis, catheter dysfunction, and even cranial retrograde injection, in which the infusate is directed to the head instead of the central circulation [2].

In this article, we focus on the rare pigtail features on chest X-ray after central venous catheterization, on their causes, and on measures to eliminate the risk of malpositioning or, if malpositioning already has happened, to recognize and manage the incident appropriately.

Case 1

In a 73-yr-old patient suffering with right-sided malignant infarction of the medial cerebral artery region of the brain, a CVC was placed in the left subclavian vein according to the Seldinger technique. Aside from meeting a slight resistance during advancement of the guide wire, no problems of catheter placement were reported. Venous blood could be aspirated easily and the transudated venous pressure measurements showed a typical venous waveform pattern. However, despite sinus rhythm while using electrocardiography (ECG) to guide the CVC positioning, a typical pattern of ECG changes could not be detected.

Assuming malposition of the original CVC, a second catheter was placed through the left brachiocephalic vein. Here, the ECG guidance worked as expected and the catheter was advanced until a maximum P-wave (P\text{max}) pattern could be detected.

A frontal chest radiograph demonstrated the first catheter curling up in the azygos arch (Figure 1). The second CVC was
shown to be positioned correctly in and running along the long axis of the SVC. A second (lateral view) radiograph was taken, applying water-soluble contrast medium through the misplaced catheter (Figure 2). Here, parts of the azygos arch as well as the SVC were emphasized by the runoff of contrast medium.

**Case 2**

In an intensive care patient, a CVC was inserted through the left internal jugular vein. The cannulation was described as having proceeded without problems. However, upon being interviewed, the operator revealed that he had met a slight elastic resistance at 10–12 cm while advancing the guide wire. The CVC insertion then proceeded without further problems, but, coincident with the ECG guidance, the P-wave amplitude did not change during advancement of the catheter. Clinically, venous blood could be aspirated easily and the transduced venous pressure measurements showed a typical venous waveform pattern.

Assuming malposition of the original CVC, a second catheter was placed through the left internal jugular vein. Here, the ECG guidance worked as expected and the catheter was advanced until a P_max pattern could be detected.

On frontal chest X-ray, the first catheter was found to have curled in projection of the aortic knob (Figure 3). Aortic misplacement could be ruled out by already proven venous pressures. The second CVC, placed at P_max using ECG guidance, was placed appropriately, outside the right atrium and along the long axis of the SVC. The malpositioned CVC was removed uneventfully.

**Case 3**

In another ICU patient on vasopressor support, a CVC had to be inserted. Here, no resistance was met during advancement of the guide wire and the catheter. ECG guidance worked properly while using an Alpha card® syringe (which uses the sodium chloride–filled distal lumen of the CVC as an electrical conductor). However, as could easily be seen on chest radiography, the CVC tip was curled in the SVC (Figure 4). A second X-ray was taken while injecting a water-soluble contrast medium through the distal lumen (Figure 5).
The answer to this riddle was the type of catheter used—a COOK® curved tip, triple-lumen CVC designed to reduce the risk of SVC perforation, especially in left-sided approaches.

**DISCUSSION**

Central venous catheterization is an essential component of current clinical practice. But the insertion of CVCs is not without risk. Numerous complications described both during placement of the catheter and later during long-term maintenance, are hazardous to patients and expensive to treat. Malposition of the catheter tip is one of such complication, which usually involves placement of the catheter in various large tributaries of the SVC.

**Anatomy**

Variations in venous anatomy as well as challenging body habitus (e.g., obesity or large breasts) are believed to contribute to primary CVC malpositioning and tip migration and thus to secondary malpositioning as well.

Two types of variants in venous anatomy are recognized: congenital and acquired. In patients with congenital variations, they are usually discovered incidentally on imaging after CVC placement [2]. Although these variations are usually asymptomatic, they can make the radiologic location of the CVC tip difficult to discern. A common congenital variation with clinical significance is a persistent left-sided SVC, which is seen in 0.3% of healthy patients and 4% of patients with congenital heart disease [6,7].

Other relevant congenital variations in venous anatomy include a dominant supreme (highest) intercostals venous drainage to the hemiazygos vein, inferior vena cava (IVC) variations, partial anomalous pulmonary venous drainage, and azygos vein abnormalities in origin, course, tributaries, anastomoses, and termination [2,8].

Acquired variations in venous anatomy are more common than congenital variations and can be external or internal in origin. More than 85% of external vessel distortions are caused by compression secondary to malignancy (often lung cancer, breast cancer, lymphoma, or germ cell tumors) [2]. Benign causes of external distortion include substernal goiter, thymoma, cystic hygroma, and histoplasmosis. Also, lung collapse or pleural effusions can shift venous structures such as the SVC away from the midline. Internal vessel distortion can be caused by thrombosis or stenosis. The risk of thrombosis can be increased by recent surgery, inflammation, malignancy, immobilization, hemodialysis, chemotherapy, and pregnancy, and vessel stenosis has been associated with overuse of any vessel, subclavian cannulation, and central venous access from the left side of the neck [2,8].
In normal anatomy, the azygos vein (v. azygos; vena azygos major) begins opposite the first or second lumbar vertebra, by a branch, the ascending lumbar vein, or sometimes by a branch from the right renal vein, or from the IVC. It enters the thorax through the aortic hiatus in the diaphragm, and passes along the right side of the vertebral column to the fourth thoracic vertebra, where it arches forward over the root of the right lung, and ends in the superior vena cava, just before that vessel passes through the pericardium [9].

The left vein (v. intercostalis suprema sinistra) runs across the arch of the aorta and the origins of the left subclavian and left common carotid arteries and opens into the left in nominate vein. It usually receives the left bronchial vein (and sometimes the left superior phrenic vein) and communicates below with the accessory hemiazygos vein [9].

The azygos and hemiazygos system are thoracic continuations of the ascending lumbar veins within the posterior aspect of the thorax. Usually, the azygos arch drains into the posterior aspect of the SVC approximately 1 cm below the junction of the right and left brachiocephalic (in nominate) veins. The hemiazygos system drains into the left brachiocephalic vein via the left superior intercostal vein [9,10].

Anatomically, when compared with the right brachiocephalic vein, the left brachiocephalic vein is more horizontal and its junction with the SVC usually occurs almost a right angle [9]. Accordingly, guide wires inserted from the left side may be advanced inadvertently into an inferior tributary of the brachiocephalic vein, leading to CVC malpositioning [11,12].

Also, guide wires from the left while being advanced will always contact the lateral wall of the SVC before (hopefully) turning round into the SVC. This seems to be the mechanism for misplacement of catheters into the azygos arch. Hence, the risk of azygos arch cannulation is substantially increased if catheters are inserted through left-sided veins [13].

In our Case 1, the azygos arch drained close to the junction of the brachiocephalic veins. We blame this anatomical variation for causing the repeated difficulties in advancing the guide wire into the SVC, since the guide wire and the catheter kept getting caught in the azygos arch.

Malposition in the azygos arch occurs in 1.2% of central venous cannulations [13].

In one series, 19% of catheters misplaced into the azygos arch resulted in perforation [13].

In our Case 2, the pigtail feature of the CVC tip in projection on the aortic knob is pathogenetic of CVC misplacement in the left superior intercostal vein. This is due to the course of the left superior intercostal vein in the neighborhood of the aortic arch (Figure 6) [9,14].

However, one should bear in mind that malposition of the catheter tip may occur not only at the time of insertion, but also later, as a result of spontaneous migration due to anatomic positioning or pressure changes within the thoracic cavity, an effect augmented by repeated forceful coughing. Also, intravenous therapy is often administered faster than recommended, as workload for nursing staff is steadily increasing.

A high flow rate at the catheter tip may produce a jet effect, causing displacement of the tip backwards and upwards [Figures 7-9] [15].

Malposition, whether aberrant into another vein or simply due to poor positioning, can have serious consequences [16]. Perforation, thrombosis, vascular stenosis, and even complete vascular occlusion in children have been reported with CVC malpositioning in the azygos arch [11].

It is difficult to ensure correct placement of a CVC in the SVC in the absence of either ECG guidance or ultrasound or pressure monitoring. Any difficulty in advancing a guide wire or catheter is the vital clue that should alert the operator that misplacement may be occurring. Also, catheter dysfunction and/or (in the conscious patient) persistent, intermittent, or exacerbating chest or back pain after central infusion always require immediate chest radiography (frontal and lateral), eventually with contrast material. A misplaced CVC in the azygos arch or left superior intercostal vein must be removed immediately.

Mechanisms of malpositioning

While the mechanisms of CVC malpositioning are not well understood...
Measures for prevention

ECG guidance during CVC placement is an excellent technique that excludes unrecognized malpositioning. This technique was first described by Hellerstein and colleagues in 1949. With an intraluminal wire or with saline as an electro conductive medium, the tip of the catheter is used as an electrode to obtain the intravascular/intra-atrial ECG (Figure 10) [21]. As the catheter tip is at the junction of the SVC and the right atrium (RA), the P-wave amplitude increases to P\text{max} (Figure 11) [22,23]. Further advancement of the catheter tip either shows a decrease in P-wave amplitude or turns the P-wave biphasically [22,23]. Almost 40 years ago, neurosurgeons used this technique for the first time to place ventriculo-atrial shunts. At that time, other applications of the ECG-guidance technique were used for positioning pacer probes and for intra cardiac diagnosis of complex cardiac dysrythmias.

Many clinical studies have shown that ECG guidance during CVC placement is a well-proven tool for reducing malpositioning [21-26]. For other methods, such as chest radiography or formulas, evidence in this respect is lacking. Chest radiography is useful for recognizing malpositions after CVC placement and for detection of mechanical complications. Formulas can give only an assumption of insertion depth, which is of little help in clinical practice, due to the individuality of each patient.

ECG-guided CVCs can be positioned exactly, obviating the need for position control via chest radiography. However, for exclusion of mechanical complications (e.g., pneumothorax), a chest X-ray is mandatory. ECG guidance, however, can be difficult in patients with arrhythmias.

Placing a CVC without fluoroscopic or ECG guidance results in malpositioning in at least 15% of patients, and an incidence of complications of about 12%.

When available, transesophageal echocardiography (TEE) to assist during placement of the CVC is a highly accurate method of ensuring a location in the SVC or at the SVC/RA junction [22-24]. With reservations, this also holds true for transthoracic echocardiography (TTE).

Ultrasound examination is performed through epigastric and subcostal acoustic windows along the short heart axis. This enables the simultaneous visualization of the SVC, IVC, and RA. A 10-mL syringe, containing 9 mL of saline and 1 mL of air, is agitated until a homogeneous mixture of saline and air is achieved. Subsequently, this syringe is attached to the lumen of the catheter, ending at its tip. Next, 5 mL of the solution is injected rapidly through the catheter. Interpretation of the micro bubble test should be performed using the criteria described by Vezzani and colleagues (Table 1) [27]. A stream of micro bubbles with laminar jet flow from the SVC within 1 to 2 seconds after the injection indicates correct catheter location.

After placement of all CVCs, a chest X-ray should be performed for exclusion of mechanical complications and CVC malpositions. A posterior or anteroposterior film is usually adequate; if not, a lateral view may be taken. If uncertainty still exists, a venogram through the catheter should be performed for precise localization [7,13] A properly placed subclavian or internal jugular catheter should run parallel to the shadow of the SVC.

Differential diagnosis of left-sided thoracic CVCs will help
categorize the type of malposition-extra vascular in pleura, pericardium, or mediastinum; arterial; in a vein other than the superior vena cava; or a persistent left SVC (LSVC) [7,28,29].

- An extravascular malposition can be excluded clinically by free venous backflow through all catheter lumina and the absence of clinical symptoms.
- Malposition in the descending aorta should be ruled out by transduction of the venous pressure waveform.
- A water-soluble contrast medium-enhanced lateral chest X-rays the quickest and most inexpensive reliable method for differentiating a left-sided malposition from a correct position in a persistent LSVC.
- A catheter tip overlying the anterior mediastinum is located in the left internal mammary vein.
- A catheter tip overlying the middle mediastinum is placed in an LSVC or left pericardiophrenic vein.
- A catheter inserted deep into the left pericardiophrenic vein runs a characteristic course on frontal chest x-ray along the cardiac border [7,28].
- Contrast media run-off will allow differentiation of a pericardiophrenic vein and persistent LSVC; contrast media run-off is poor in the pericardiophrenic vein.

In an LSVC, the run-off is good.

- A catheter tip overlying the posterior mediastinum is placed in the left superior intercostal vein or the descending aorta [7,28,29].
- Contrast media will extravasate if the catheter tip is placed extravascularly.
- Because an LSVC runs in front of the descending aorta, on frontal chest radiography, a catheter in an LSVC can easily be confused with a malposition in the descending aorta.
- Further methods to differentiate left-sided catheters and venous anomalies are TEE, magnetic resonance imaging, and computed tomography.

For the differential diagnosis of curled CVCs to either right or left of sternum, please refer to Table (2).

Malpositioning of CVCs is usually asymptomatic. Placement in the superior intercostal, azygos, and hemiazygos veins may, in awake patients, result in back pain while flushing the catheter. Though characteristic chest pain often provides a clue to the erroneous catheter position, catheter malposition is more often identified by a post-procedure chest radiograph.

If the course of a misplaced catheter can be correctly identified as not lying within a vulnerable structure, then it can be safely removed. If the misplaced catheter is lying within or traversing large and incompressible arteries or veins, it should not be removed before consideration of what is likely to happen once it is removed. Advice and further imaging should be sought, typically in conjunction with interventional radiology or vascular surgery. With regard to misplaced CVCs, in the short term, a useful aide mémoire is: “If in doubt, don’t take it out” [8,30].

### Table 1: Criteria for Classification and Interpretation of Microbubble Test.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>No bubbles</td>
<td>Negative test: an aberrant tip position must be considered</td>
</tr>
<tr>
<td>Few bubbles or appearance time &gt; 2 sec</td>
<td>Test to be repeated: if confirmed, possible misplacement</td>
</tr>
<tr>
<td>Numerous bubbles and turbulent flow coming from RA within 2 sec</td>
<td>Negative test: intra-atrial positioning</td>
</tr>
<tr>
<td>Numerous bubbles and laminar flow coming from SVC</td>
<td>Positive test: CVC tip correctly placed in SVC</td>
</tr>
</tbody>
</table>

**Abbreviations:** CVC: Central Venous Catheter; RA: Right Atrium; SVC: Superior Vena Cava

### Table 2: Differential Diagnosis of Curled CVCs to Right or Left of Sternum.

<table>
<thead>
<tr>
<th>Anatomy</th>
<th>CXR ap view</th>
<th>CXR lat view</th>
<th>Contrast media application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azygos arch</td>
<td>Right of sternum</td>
<td>Dorsal mediastinum</td>
<td>Runoff in SVC</td>
</tr>
<tr>
<td>Superior intercostal vein</td>
<td>Left of sternum, characteristic “bend” in projection to aortic knob</td>
<td>Dorsal mediastinum</td>
<td>Runoff in hemiazygos vein</td>
</tr>
</tbody>
</table>

**Abbreviations:** CXR: Chest Radiograph; ap: antero-posterior; lat: lateral; SVC: Superior Vena Cava

### CONCLUSIONS

Knowledge of normal and variant anatomy must be considered essential for all those involved in the insertion and assessment of central venous catheters. Moreover, during guide wire insertion, it will be prudent to feel for any obstruction or change in resistance that may denote change in direction or coiling. Any difficulty in advancing a guide wire or catheter is the vital clue that should alert the operator that misplacement may be occurring.

In patients with sinus rhythm, the only low-key and reliable bedside method for assessing CVC tip position is ECG guidance while advancing the catheter. Alternatively, TTE can be performed, applying an agitated saline solution through the catheter to estimate CVC tip position.

Post procedural chest radiography should be performed after each CVC insertion for assessment of malpositioning and contingent mechanical complications.

Always bear in mind that, while CVCs are beneficial devices in modern medicine, they also carry particular risks. To deal with them, awareness, knowledge, and experience are key.

### REFERENCES


