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ORIGINAL ARTICLE

Radiographic signs of non-venous placement of intended central venous catheters in children

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Abstract
Background Central venous catheters (CVCs) are commonly used in children, and inadvertent arterial or extravascular cannulation is rare but has potentially serious complications.
Objective To identify the radiographic signs of arterial placement of CVCs.
Materials and methods We retrospectively reviewed seven cases of arterially malpositioned CVCs on chest radiograph. These cases were identified through departmental quality-assurance mechanisms and external consultation. Comparison of arterial cases was made with 127 age-matched chest radiographs with CVCs in normal, expected venous location. On each anteroposterior (AP) radiograph we measured the distance of the catheter tip from the right lateral border of the thoracic spine, and the angle of the vertical portion of the catheter relative to the midline. On each lateral radiograph we measured the angle of the vertical portion of each catheter relative to the anterior border of the thoracic spine. When bilateral subclavian catheters were present, the catheter tips were described as crossed, overlapping or uncrossed.
Results On AP radiographs, arterially placed CVCs were more curved to the left, with catheter tip positions located farther to the left of midline than normal venous CVCs. When bilateral, properly placed venous catheters were present, all catheters crossed at the level of the superior vena cava (SVC). When one of the bilateral catheters was in arterial position, neither of the catheters crossed or the inter-catheter crossover distance was exaggerated. On lateral radiographs, there was a marked anterior angulation of the vertical portion of the catheter (mean angle 37±15° standard deviation [SD] in arterial catheters versus 5.9±8.3° SD in normally placed venous catheters).
Conclusion Useful radiographic signs suggestive of unintentional arterial misplacement of vascular catheters include leftward curvature of the vertical portion of the catheter, left-side catheter tip position, lack of catheter crossover on the frontal radiograph, as well as exaggerated anterior angulation of the catheter on the lateral chest radiograph.

Keywords Arterial cannulation · Central venous catheter · Chest · Children · Complication · Radiography

Introduction

Central venous catheters (CVCs) are commonly used in the pediatric population for hemodynamic monitoring, intravenous drug therapy, hyperalimentation, hemodialysis and rapid volume administration. Despite the use of US or fluoroscopic guidance during CVC insertion to aid in proper positioning, a wide range of serious complications can occur [1–5]. Several studies have shown that inadvertent arterial cannulation occurs at rates from 0.8 to 2.2% in children [6, 7] and from 1.1 to 3.7% in adults [8, 9]. Clinical signs of arterial placement (e.g., backflow of bright red blood, arterial wave tracing on pressure transducer, increased resistance with fluid/medication administration) are not always apparent, particularly in the critically ill, but post-procedure chest radiograph findings should alert clinicians and radiologists to possible arterial placement of a CVC [10–12].

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The goal of this study was to identify the key radiographic findings of arterial placement of CVCs in children through comparison of chest radiographs of arterially malpositioned CVCs with properly positioned venous CVCs. In addition, we describe one case of inadvertent epidural placement of a CVC and two cases in which the chest radiograph mimicked arterial placement of a CVC.

Materials and methods

After institutional review board approval, we performed a retrospective search of the quality assurance database for the Department of Radiology at our institution for cases of non-venous placement of CVCs occurring between Dec. 30, 1998, and Dec. 30, 2014. The mechanisms by which cases are identified and reported include a hospital-wide sentinel event reporting system, a radiologist double-read process, and reported discrepancies that arise during weekly multidisciplinary departmental conferences [13]. We identified seven cases of suspected arterially malpositioned CVCs on chest radiographs or fluoroscopic imaging. Of these, five cases were confirmed by clinical or surgical follow-up to be arterial in position, and two were identified as properly placed venous catheters that mimicked arterial placement. In addition, there was one case of an inadvertent epidural placement of a CVC. We also reviewed two cases of arterially malpositioned CVCs referred for consultation from outside institutions.

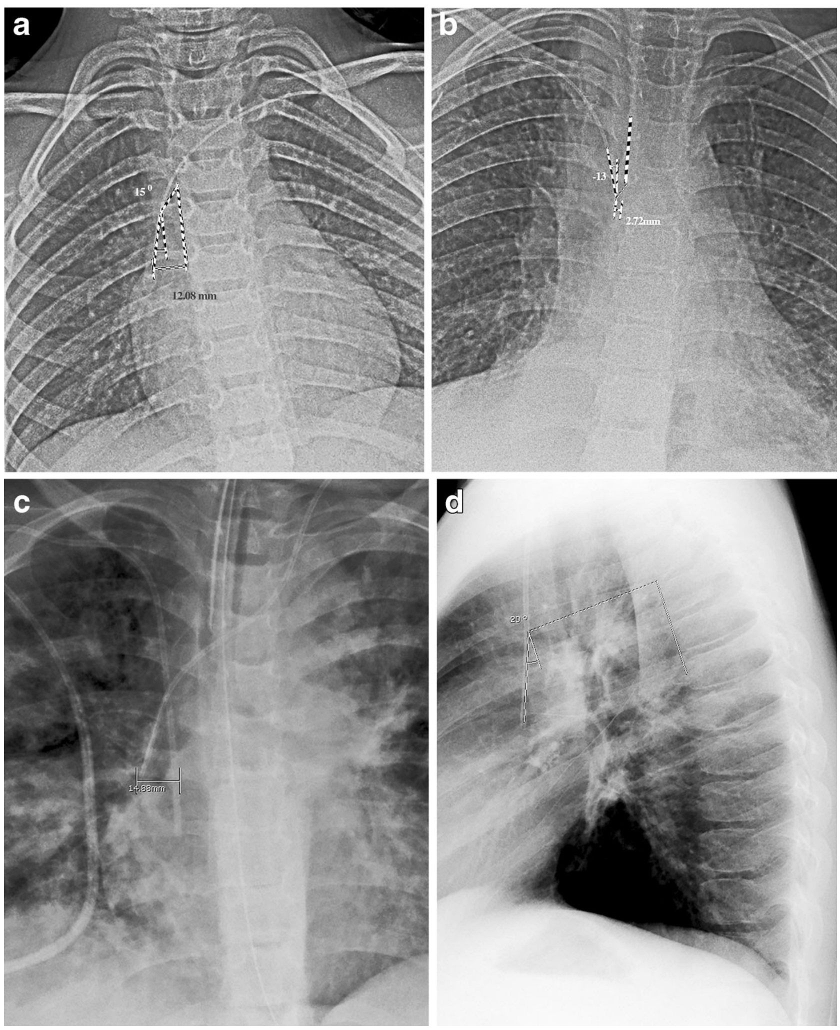


Fig. 1 Normal catheter tip location. **a** Left-side venous catheter. Anteroposterior (AP) chest radiograph shows the vertical portion of the catheter angled at 15° relative to the right of the right lateral border of the thoracic spine. The tip of the catheter is located 12 mm to the right of the right lateral border of the thoracic spine. A positive angle denotes a catheter course to the right of midline (*clockwise*). **b** Normal right-side venous catheter. AP chest radiograph shows the vertical portion of the catheter angled at −13° relative to the right of the right lateral border of the thoracic spine. The tip of the catheter is located 3 mm to the right of the right lateral border of the thoracic spine. A negative angle denotes a catheter course to the left of vertical (*counterclockwise*). **c** Normal bilateral venous catheters. AP chest radiograph shows normal crossed catheter tips within the superior vena cava. **d** Normal venous catheter. Lateral chest radiograph shows measurement of the lateral angle (20°) of the catheter relative to the anterior border of the thoracic spine measured between T4 and T6 vertebral bodies

Table 1 Cases of arterially malpositioned central venous catheters

Case	Age	Gender	Line type/insertion procedure	Catheter tip position	Time and method of confirmation	Complications/outcome	Treatment
1	32 mos	F	Right PICC, basilic vein (4Fr, double lumen) under US guidance and confirmed with fluoroscopy	Ascending aorta	14 days Arterial blood gases and waveform on pressure transducer	Small area of spasm or partial stenosis of brachial artery at insertion site noted on US on day of removal of line	Pull/pressure technique
2	35 mos	M	Right subclavian port-a-cath (7Fr, double lumen) under fluoroscopic guidance	Ascending aorta	<1 day Fluoroscopic line study	None	Pull/pressure technique
3	19 yrs	F	Right PICC, basilic vein (5Fr, double lumen) under US guidance	Ascending aorta	<1 day Clinical diagnosis by ICU team	None	Pull/pressure technique
4*	3 yrs	F	Left subclavian port placed under fluoroscopic guidance	Ascending aorta	2 years Chest CT and echocardiography	Headache with infusions of chemotherapy Mild cognitive delay of unclear etiology	Pull/pressure technique
5*	5 mos	M	Left subclavian port placed under fluoroscopic guidance	Ascending aorta	2 hours Arterial gases	None	Pull/pressure technique
6	3 yrs	F	Left subclavian (6Fr, double lumen) attempted under fluoroscopic guidance	Ascending aorta	<1 hour Clinical diagnosis, fluoroscopic line study, surgical arterial repair	Intraoperative development of hypotension, large left hemothorax and pneumothorax from inadvertent subclavian artery cannulation Left phrenic nerve injury Left innominate vein laceration Fully recovered	Emergent sternotomy with primary closure of damaged vessels, double chest tube insertion
7	7 yrs	M	Left subclavian (6Fr, double lumen, tunneled) confirmed with fluoroscopy	Transverse aorta	28 days Head/neck MRI/MRA performed for neurological symptoms	Neurological symptoms (confusion, seizure activity) concurrent with TPA infusion on 28th day; malpositioned catheter was in place	Pull/pressure technique

*Cases obtained from outside institutions

F female, *Fr* French, *M* male, *MRA* magnetic resonance angiography, *PICC* peripherally inserted central catheter, *TPA* tissue plasminogen activator

ICU intensive care unit

The study was carried out at a tertiary free-standing academic children's hospital, and all imaging studies at our institution were interpreted by pediatric radiologists. All radiographic studies were reviewed by a senior radiologist with more than 30 years' experience.

To identify the radiographic signs of arterially positioned CVCs in comparison to correctly (venous) positioned CVCs, we randomly selected 127 chest radiographs on 65 age-matched children with appropriately placed venous central lines as a normal control group. We included all types of CVCs (peripherally inserted central catheters [PICCs], tunneled and non-tunneled CVCs, and implanted ports) that were inserted from an upper extremity vein or subclavian vein within our control population under the assumption that the catheter course within the great veins does not differ greatly between types of CVCs. Ninety anteroposterior and 37 lateral radiographs were reviewed. Eleven of these 65 control children had normal, bilateral CVCs, accounting for a subset of 16 anteroposterior and 6 lateral radiographs reviewed. We excluded control patients with radiographic studies showing marked rotation, poor image quality, more than mild scoliosis, or evidence of thoracic surgeries, mediastinal masses or chest pathology leading to mediastinal shift.

On anteroposterior (AP) radiographs of case studies and control patients, the catheter tip was described according to its location relative to the right lateral border of the thoracic spine. The vertical course of the catheter was described as curved to the right (positive angle) or to the left (negative angle) of the right lateral border of the thoracic spine (Fig. 1). When bilateral subclavian catheters were present, the catheter tips were described as crossed (Fig. 1), overlapping or uncrossed. On lateral radiographs we measured the angle of incidence of the vertical portion of the catheter with respect to the anterior border of the thoracic spine between the 4th and 6th vertebral bodies (Fig. 1).

Results

Table 1 describes the seven cases of arterially malpositioned catheters identified in this series. All catheters were inserted via subclavian approach. Central venous catheters were surgically placed, and all PICC lines were placed by the hospital PICC service. The age range of patients with arterial CVCs was 5 months to 19 years, with variable times to diagnosis of arterially malpositioned CVC.

Three catheters were inserted from a right-side approach (Table 1, cases 1–3). All three chest radiographs showed an unusual leftward course of the catheter to the left of the thoracic spine on the AP view (Figs. 2 and 3). No lateral radiographs were obtained.

Among the four left-side arterially placed CVCs (Table 1, cases 4–7), 18 radiographic studies (15 AP chest radiographs, 8 lateral chest radiographs, two fluoroscopic studies and a lateral scout image from a chest CT examination) were available for review. Catheters inserted from a left-side approach had a more variable appearance, depending on patient rotation. However, a catheter tip position to the left of the right lateral border of the thoracic spine, and an exaggerated leftward curve of the vertical portion of the catheter on the AP chest radiograph were both strongly suggestive of an arterial placement (Figs. 4, 5 and 6). Two patients had bilaterally inserted catheters, one catheter in the normal intravenous location and the other in the ascending aorta. In one child, the catheter tips did not cross (Fig. 4). In the second patient, the catheters crossed, but the distance between catheter tips was 30.7 mm, much larger than the expected width of the SVC (Fig. 3). On nine lateral chest images available for review, the

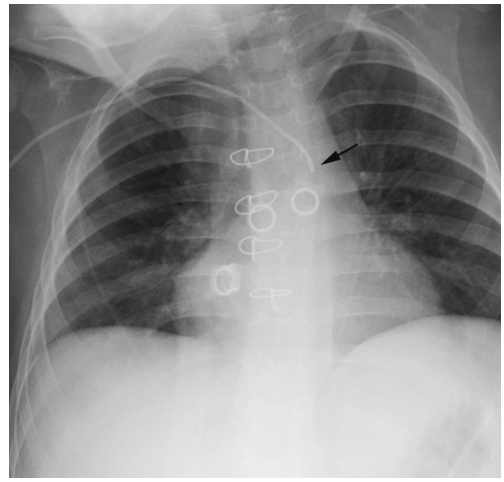


Fig. 2 Case 1, a 32-month-old girl with heart failure and bilateral ventricular assist device. Anteroposterior chest radiograph shows an arterial catheter inserted via right subclavian approach with its tip in the ascending aorta (*arrow*), adjacent to the arterial cannula of the assist device

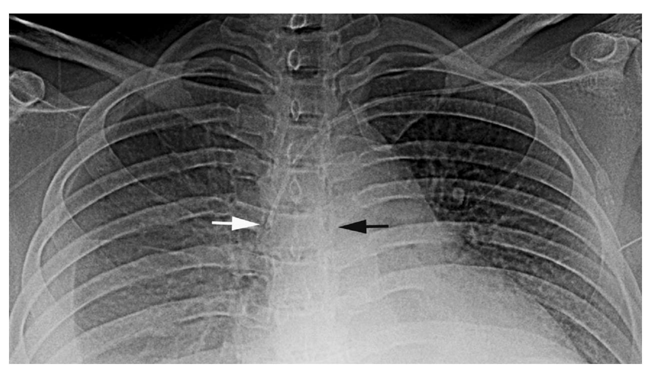
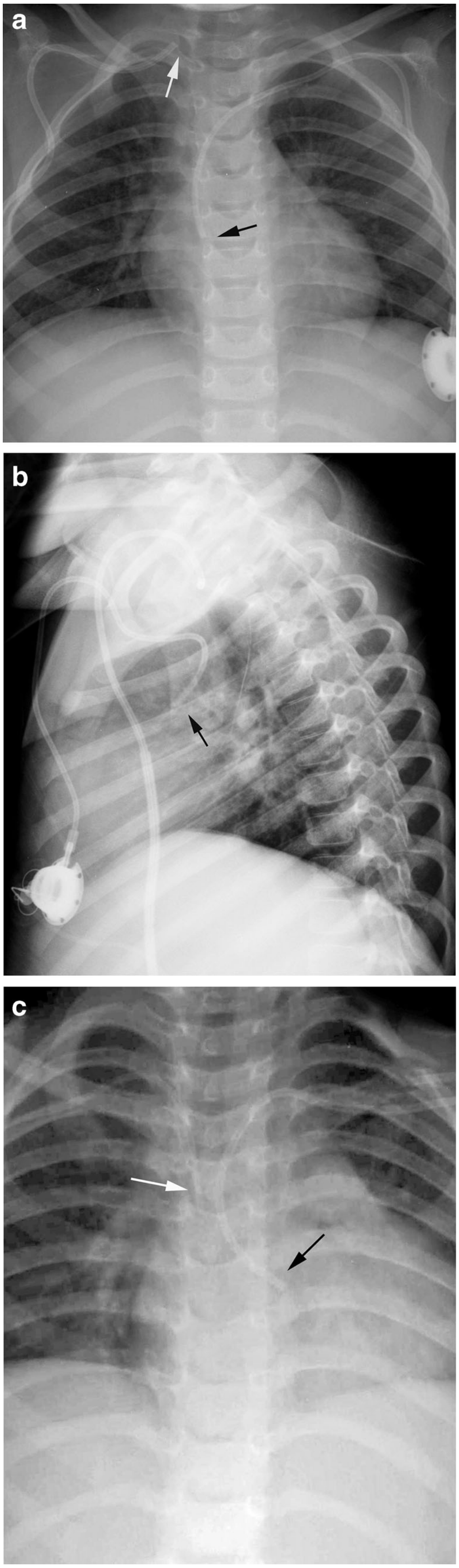


Fig. 3 Case 3, a 19-year-old woman with renal sarcoma. Anteroposterior chest radiograph shows a normally placed left subclavian venous catheter (*white arrow*) and an arterially placed catheter inserted via a right subclavian approach (*black arrow*). Note course of arterial catheter to left of the thoracic spine, exaggerated inter-catheter crossover distance, and moderate right pleural effusion



◀ **Fig. 4** Case 4, a 3-year-old girl with acute lymphocytic leukemia. **a** Anteroposterior (AP) chest radiograph shows a right subclavian venous catheter inserted via a right subclavian approach, with its tip in right subclavian vein (*white arrow*). An aortic catheter inserted via a left subclavian approach (*black arrow*) shows subtle leftward curvature of the catheter, with the catheter tip overlying the right lateral border of the thoracic spine. **b** Lateral chest radiograph shows exaggerated anterior angulation of the arterial catheter (*arrow*). **c** AP chest radiograph obtained several days later shows a normally placed venous catheter (*white arrow*) and an arterially placed catheter in the ascending aorta (*black arrow*). Note that the catheters do not cross, and there is an exaggerated leftward angulation of the arterial catheter, with tip position to left of the thoracic spine

vertical portion of the catheter showed an exaggerated anterior angulation (Figs. 4 and 6). Lateral angles of left-side arterial catheters were all markedly positive (i.e. anteriorly angulated) compared to the lateral angles of both right- and left-side venous CVCs, which had a more vertical course of the catheter. No lateral views of right-side arterial CVCs were available for review.

We identified three cases in which chest radiographs mimicked arterial placement of a venous catheter. The first case was a 17-month-old girl with a right-side thoracic neuroblastoma. Chest radiographs showed an unusual course of a left-side catheter on the AP radiograph and an exaggerated anterior angulation on the lateral radiograph, with a lateral angle measurement of 50° (Fig. 7). CT confirmed intravenous placement in the SVC, which was anteriorly displaced by a posterior mediastinal mass with right paratracheal extension (Fig. 7). In the second case, a marked leftward curve with left-side tip position is present on chest radiograph (Fig. 8). CT imaging confirmed intravenous location within the SVC, which was displaced to the left as a result of an intra-atrial baffle (Mustard procedure) performed for an underlying transposition of the great vessels (Fig. 8). The third case was a

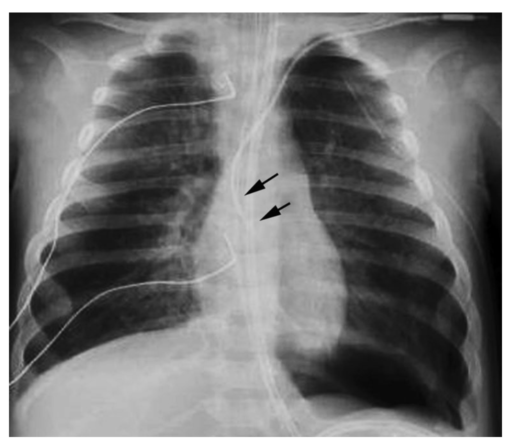


Fig. 5 Case 5, a 5-month-old boy with respiratory failure and pneumothorax caused by acute viral pneumonia. Anteroposterior chest radiograph shows leftward curve and left-side tip position of the arterial catheter (*arrows*), placed via a left subclavian approach (Image courtesy of Dr. Michael A. DiPietro)

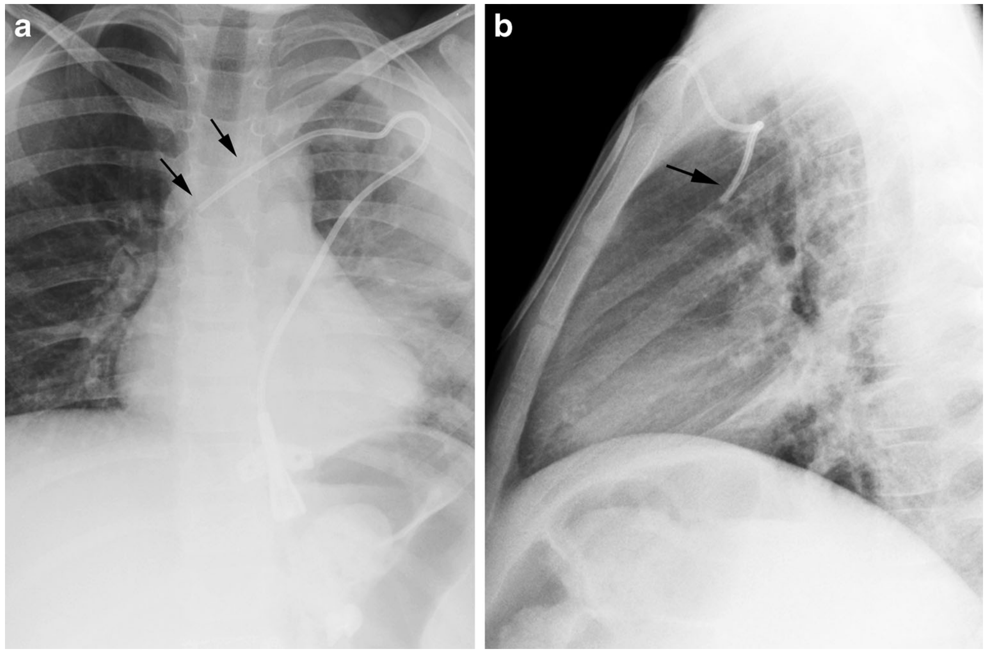


Fig. 6 Case 7, a 7-year-old boy with combined immunodeficiency disorder. **a** Anteroposterior chest radiograph shows an arterially placed catheter via a left subclavian approach, with an unusual oblique course of the catheter (*arrows*) and a large left pleural effusion. **b** Lateral chest radiograph shows exaggerated anterior angulation of catheter (*arrow*) in the ascending aorta

neonate in whom fluoroscopic imaging showed inadvertent placement of a vascular catheter within the epidural space during surgical placement (Fig. 9).

Discussion

Arterial placement should be suspected on AP chest radiograph by a marked, leftward curvature of the vertical portion of the catheter or a catheter tip located to the left of the right lateral border of the thoracic spine. On the lateral chest radiograph, a marked anterior curvature of the catheter is highly suggestive of arterial placement. Bilateral venous catheters should normally cross on the AP chest radiograph during their course within the SVC. Failure to cross, or an exaggerated distance between the catheter tips, should raise the possibility that one of the catheters is in arterial location.

Because of the vertical, non-curving course of the SVC, rotation of an AP or lateral chest radiograph should cause little, if any, angulation of the vena cava and a normally placed venous catheter. The ascending aorta, however, curves as it arises from the posteriorly located left ventricle and courses superiorly to form the aortic arch. A catheter located in the ascending aorta is located farther left of the expected position of the SVC. Its vertical course is angled to the left of midline on the AP chest radiograph and anteriorly on the lateral chest radiograph. In addition, small changes in chest rotation during radiography have an exaggerated effect on the curvature and location of arterial catheters. None of the normal venous catheters had a tip position left of the anatomical midline.

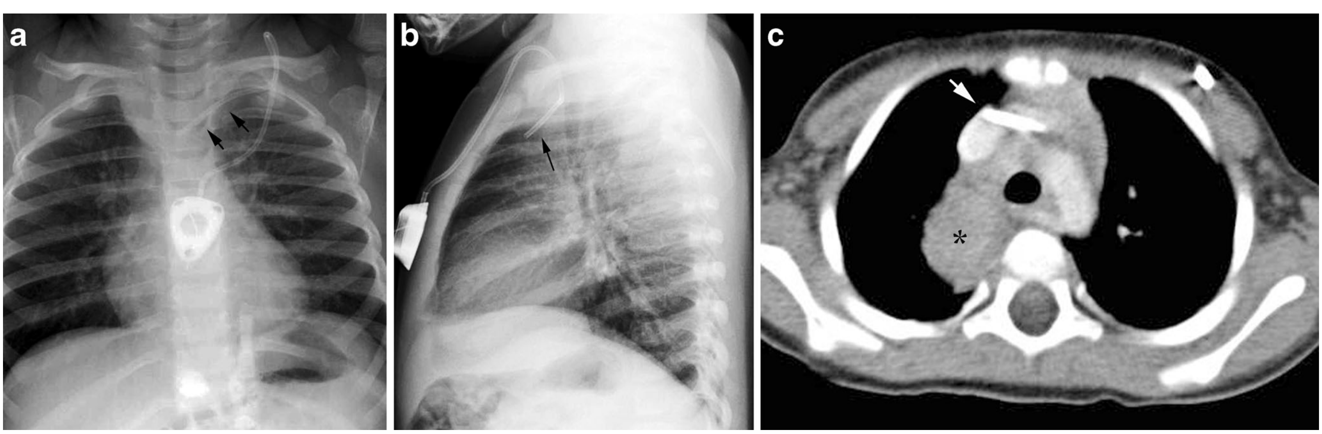


Fig. 7 Venous catheter position mimicking arterial placement in a 17-month-old girl with neuroblastoma. **a** Anteroposterior chest radiograph shows an oblique course of the venous catheter (*arrows*), inserted via a left subclavian approach. **b** Lateral chest radiograph shows exaggerated anterior angulation of the venous catheter (*arrow*). c Axial contrast-enhanced CT at level of the innominate vein shows anterior displacement of the superior vena cava and catheter (*arrow*) by a posterior mediastinal mass (*asterisk*) with right paratracheal extension

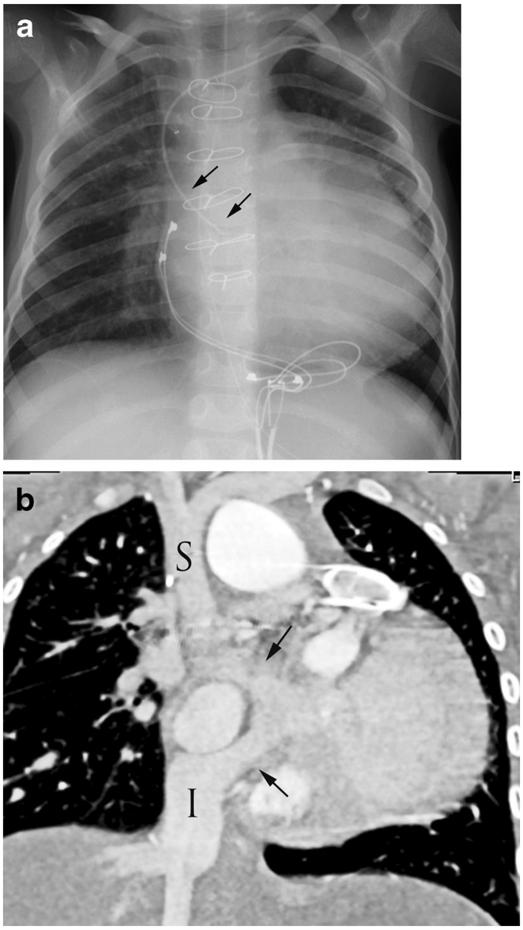


Fig. 8 Venous catheter location mimicking arterial placement in a 4-year-old boy with repaired transposition of the great vessels. **a** Anteroposterior chest radiograph shows leftward curvature and left-side tip position of the venous catheter (*arrows*), resembling arterial placement. **b** Coronal reconstruction of contrast-enhanced CT shows Mustard intra-atrial baffle with superior and inferior limbs (*arrows*) joining superior (*S*) and inferior (*I*) vena cavae to the anatomical left ventricle

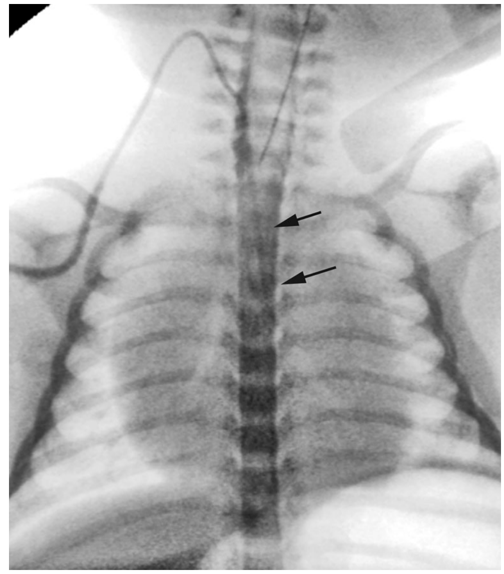


Fig. 9 Inadvertent surgical placement of a vascular catheter within the epidural space in a 6-week-old boy with suspected osteopetrosis. Anteroposterior fluoroscopic image of the chest during line injection shows an intended right jugular venous catheter (*arrows*) within the thoracic epidural space outlined by injected contrast material

As shown in this study, normally placed bilateral venous catheters always cross within the SVC. We postulate that venous catheters have a tendency to continue in a relatively straight line until deflected inferiorly by the wall of the SVC. Catheters placed from a left subclavian approach are deflected by the lateral wall, and those placed via a right subclavian approach are similarly deflected by the medial wall of the vena cava, resulting in a crossed path within the lumen of the SVC. When an arterial catheter is placed via a left subclavian approach, there is no possibility of crossing with a venous catheter placed via a right subclavian approach because the left arterial catheter is medial to the vena cava (Fig. 4). When the arterial catheter is placed via a right subclavian approach, its course is medial to the SVC, and the distance between its tip and the tip of a normally placed left-side venous catheter may be wider than expected (Fig. 3).

CVC placement in children is a common and generally safe procedure. In a series of more than 1,400 consecutive catheterizations in children over a 10-year period, Johnson et al. [6] reported a 3.1% perioperative complication rate, including arterial puncture in 19 cases (1.5%). The frequency of complications related to prolonged arterial placement in children is not known. We found only one case report — a 15-year-old boy who had a focal infarct of the basal ganglia associated with misplacement of a PICC line in the subclavian artery that was left in place for 10 days [4]. Neurological symptoms with infusion through an arterially placed CVC are rare in adults and can lead to permanent weakness, disability and death [5]. All patients at our institution recovered fully with no permanent neurological impairment. Studies in children and adults have suggested that post-procedural chest radiography can be safely eliminated and may not be cost-effective when CVC insertion is accompanied by fluoroscopic guidance [8, 14]. However our cases show that despite both US and fluoroscopic guidance during CVC insertion *and* the post-procedure chest radiograph, arterial placement of a CVC can occur and can have serious complications (Table 1). Treatment of the malpositioned arterial catheter in six of seven cases was by the pull and pressure technique, which in the adult population has been found to be far inferior to endovascular or open surgical repair in retrospective studies [15, 16].

The frequency of diagnostic errors related to indwelling catheters in children is also quite low, reported at 0.04% in cases reviewed over a 9-year period at our own institution [17]. Four of seven misplaced catheters in our current series were detected and removed within hours of attempted

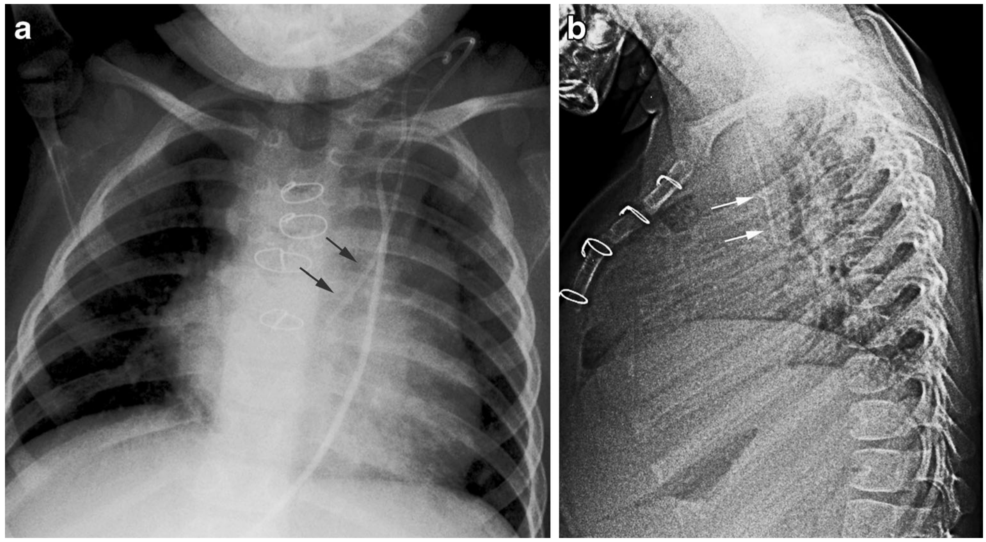


Fig. 10 Persistent left superior vena cava in a 3-year-old boy with heterotaxy syndrome. **a** Anteroposterior chest radiograph shows a venous catheter in a persistent left vena cava (*arrows*). Note the medial curve of the distal catheter as it approaches the coronary sinus. **b** Lateral chest radiograph shows a normal vertical course of the catheter (*arrows*)

placement. However, a delay in diagnosis (2 weeks to 2 years) occurred in three children.

We identified two false-positive cases in which normally placed venous catheters had catheter appearances that mimicked arterial placement. Both had anatomical distortion of the SVC as the result of either a mass or cardiac surgery. Other possible causes of arterial mimicry to consider include persistent left SVC, a variant seen in up to 2.1% of the general population [18] (Fig. 10), dextrocardia, mediastinal shift from pneumothorax or mass effect [19], and patient rotation.

In all cases of suspected arterial lines, reference to cross-sectional imaging and other clinical measures (e.g., blood gas analysis, pressure transducer measurement) should be pursued to confirm tip position.

Our study has several limitations including a retrospective design and a small sample size, which limited our ability to perform comparative statistical analyses. The number of accidental arterial placements of CVCs we report is likely an underestimation given that some arterial cannulations were not reported through the mechanisms mentioned in our Methods section.

Conclusion

Chest radiographs are useful in the diagnosis of arterial placement of CVCs, and the following radiographic findings should raise suspicion for an arterially malpositioned CVC on an AP chest radiograph: (1) a marked leftward curvature or negative frontal angle at the tip of catheter, (2) a catheter tip located to the left of the right lateral border of the thoracic spine, (3) a lack of crossover or an exaggerated inter-catheter crossover distance between bilateral catheter tips, (4) on the lateral chest radiograph, a marked anterior angulation of catheter tip relative to the thoracic spine. If any of these signs is present, further studies should be pursued to rapidly identify and treat accidental arterial cannulation and prevent complications.

Conflicts of interest None

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