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Safe Insertion of Arterial Catheters (SIA): An ultrasound-guided protocol to minimize complications for arterial cannulation

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Abstract

Direct puncture and cannulation of peripheral arteries is frequently performed in critical care and in emergency settings, mainly for hemodynamic monitoring and blood sampling. While there is abundant literature on peripheral arterial cannulation in children and adults, there is still scope for clinical improvements which may impact on patient safety. Although the radial artery is the most frequently utilized access site today, due to its superficial proximity, ease of access, and low risk of adverse events, other sites are sometimes chosen. The authors propose the Safe Insertion of Arterial Catheters (SIA) protocol, an ultrasound-guided insertion bundle applying a systematic approach to arterial cannulation, with a focus on improving insertion practices, reducing procedural complications, increasing the patient safety profile, and improving device performance.

Keywords

Radial artery, peripheral arterial catheterization, ultrasonography, best practice, outcomes, patient safety

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Introduction

One of the most performed practices within critical care and emergency medicine today is the insertion of a peripheral arterial catheter (PAC), a vascular device mainly utilized for continuous hemodynamic monitoring and repeated blood sampling. Trans-radial access procedures were introduced three decades ago for percutaneous interventional cardiology procedures,[1] and nowadays the radial artery is the most frequently accessed peripheral artery, both for its ease of access and for its low risk of complications.[2,3] In United States, the use of PAC in Intensive Care Units (ICU) has been reported in 49.2% of patients on mechanical ventilation and in 51.7% of patients requiring vasopressors,[4] with a global incidence of reported catheter failure between 4% and 25%.[5]

Other peripheral arteries, such as the femoral, brachial, axillary, and posterior tibial arteries have their place in clinical practice for specific procedures and may sometimes be regarded as an alternative if the radial artery is not suitable. Brachial arteries are generally not recommended for cannulation because of the absence of collateral flow (with consequent risk of ischemia of the forearm and hand), and the risk of median nerve injury.[6–8] The axillary artery is most often used for trans-axillary aortic valve replacement and for extracorporeal membrane oxygenation.[9,10] Although the use of these alternate arteries is growing, the radial and the femoral artery remain the cornerstones for routine arterial cannulation.[11]

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In a recent systematic review, PAC-associated complications were reported with an incidence of 8.6%, all with associated ischemia; the radial artery site presented lower associated complications (6%) and the femoral presented the highest (16%).[12] The use of the femoral and brachial arteries is next most used, with the axillary, temporal, posterior tibial, or dorsalis pedis arteries used much less frequently.[13–18] Clinicians should interpret use of these locations with caution, ensuring standardization of device placement, as these sites may frequently have higher risk of complications.

The radial artery originates from the brachial artery distally to the antecubital fossa and it ends in the distal wrist; it may present anatomical variations in 10.5% of patients. The radial artery is not significantly variable in its size; therefore, it is easy to access both in the forearm and at the wrist; the practice of preferring access at the distal wrist crease may be related to insertion practices using the blind palpation technique but is no longer considered best practice in times of widespread adoption of ultrasound guidance (USG).[19,20] A prospective, non-randomized study of 103 ICU patients demonstrated that the longevity of PACs can be increased two-fold if the artery is cannulated in the forearm area (4–10 cm from the wrist crease) rather than at the distal wrist ($P < 0.038$).[21]

Recent publications have focused on improving patient assessment, device functionality, and preventing PAC failure. The Arterial Insertion Method (AIM) has been proposed as a systematic approach designed to standardize ultrasound-guided arterial catheterization, reducing variations in practice, and improving patient assessment.[22] The RADIALS protocol[23] also focuses on simple, effective clinical strategies to improve arterial device insertion and functionality. Both the AIM and the RADIALS protocols support the optimization of PAC placement using USG.[22–24]

Several catheter material choices are available—polyurethane (PUR), polyethylene (PE), polyether-block-amide (PEBA), and polytetrafluoroethylene (PTFE) and have all been utilized in catheter manufacture. Currently, there is no substantial clinical evidence that the type of material may have any impact on the performance of the catheter or on the risk of late complications. The choice of catheter is often based on the clinician's preference, as some materials are stiffer, offer greater kink resistance, and are easier to handle (as is the case of PEBA). In vitro studies show that PE and PTFE are associated with increased risk of endothelial damage and catheter-related thrombosis, and this may be a good reason for avoiding them. Also, PTFE is a material used primarily for short peripheral venous cannulas and the use of these devices for arterial cannulation is currently discouraged.[23] In short, the current choice of materials should be preferably PUR or PEBA.

As a further adjunct to the AIM and the RADIALS protocols, the authors have developed an insertion bundle for PACs, including the best evidence from the current literature. The bundle consists of eight recommendations, each corresponding to the procedure's steps.

SIA bundle strategies

Step 1: Visual assessment of the skin

The insertion area should be inspected for bleeding, hematoma, redness, swelling, or signs of localized infection. All vascular access devices create a wound, increasing the opportunity for bacterial ingress for a variety of reasons (dirty or diseased skin, multiple puncture attempts, device pistoning from poor securement/stabilization, and frequent manipulation of device/tubing by staff). Device-associated skin complications and skin-related infections may increase the risk of bloodstream infection.[23,24]

Step 2: Assessment of appropriate collateral circulation

The presence of appropriate collateral circulation should be assessed. In the case of radial artery insertion, the Allen's Test is often used to verify adequate blood flow to the hand, assessing for adequate collateral circulation between radial and ulnar arteries. Although widespread in use, this test suffers from some limitations: (a) there is no defined cut-off time for an abnormal test; (b) the interpretation of results is subjective and operator dependent; (c) the test is not reliable in non-cooperative or sedated patients.[23,25,26] Alternative methods for assessment now include Doppler, plethysmography, and—most importantly—ultrasound.[23]

Step 3: Pre-procedural ultrasound assessment

Strong clinical evidence demonstrates superior improvements in assessment and procedural aspects of arterial device insertion with ultrasound guidance and choosing the best insertion location.[23] In PAC placement, ultrasound allows a standardized approach for vessel assessment (state of vessel health, caliber, catheter to vessel ratio), an optimized choice of the insertion location, and visualization of vessel abnormalities and anatomical structures to avoid (e.g. nerves).[8,27–30]

Step 4: Appropriate aseptic technique

The three cornerstones of appropriate technique are hand hygiene, skin antisepsis with 2% chlorhexidine in 70% alcohol, and maximal barrier precautions (including a sterile cover for the ultrasound transducer). The use of hydroalcoholic gel for hand hygiene is currently best practice.[31–33] Two decades of studies have demonstrated the superiority of 2% chlorhexidine over povidone iodine in preventing vascular device-related infections in both adults and pediatrics.[34,35] Regarding the application technique of the antiseptic, no clinical difference in microorganism reduction between the concentric circle versus the "hashtag" techniques has been demonstrated when both techniques are used equally on clean and healthy skin.[32,34,35] Current infection prevention guidelines also recommend appropriate barrier precautions (cap, facemask, sterile gown and gloves, appropriately large sterile drape, and sterile cover for the US transducer) as a minimum for arterial catheter insertion.[8,31–36]

Step 5: Local anesthesia

Arterial cannulation may be a painful procedure, particularly when multiple punctures are attempted, and this issue is often overlooked when patients are sedated and/or pharmacologically paralyzed. Local anesthesia by skin and subcutaneous tissues infiltration should be considered for controlling pain in both alert and sedated patients, and it should be included in the insertion checklist of all arterial catheterizations.[37,38] Providing pain relief may help prevent unwanted patient movement at the initial skin puncture and may also prevent inducing arterial spasm from stimulation of surrounding nerves.[39,40] Options for local anesthesia include intradermal or subcutaneous infiltration, vapo-coolant sprays, or topically applied creams, gels, or patches.[23] Clinicians should consider onset time and costs of these local anesthesia options, particularly when using topical anesthetics which may require longer application times (up to 120 min) to achieve optimal anesthetic effect at a depth of 5 mm.[41–43]

Step 6: Correct insertion technique

The consistent use of USG prevents most complications associated with puncture/cannulation of any artery (transfixion, nerve injury, pseudoaneurysm, hematoma/bleeding, wall dissection).

In a systematic review,[44] White et al. demonstrated that USG is associated with improved procedural success, with significantly greater first-attempt success rates in both adults and pediatrics, decreased cannulation time, and reductions in overall complications. The choice of US approach (short axis/out-of-plane vs long axis/in-plane) has also been investigated. A recent meta-analysis has compared the two methods, concluding that success rates were similar across both insertion techniques, with no significant differences between first-attempt success, or hematoma formation rates in the two groups. However, this review did not evaluate insertion site locations.[45]

The correct technique of PAC cannulation implies the proper choice of the insertion site, the use of ultrasound guidance, and some specific recommendations about the handling of the needle. In regard to the radial artery, a proximal insertion site (4–10 cm from the wrist, far from areas of flexion) is highly recommended.[21–24] There is increasing evidence that placement of the insertion site at the wrist increases the risk of dislodgement, mechanical failures, and infectious complications.[21–24,39] While the overall incidence of these complications are relatively low, they have the potential to be serious and may adversely affect patient outcomes. A prospective, randomized study of radial artery catheterization performed at different sites demonstrated significantly higher first-attempt and overall success rates in radial arterial catheters placed in the mid-forearm than in the wrist area, with lower rates of hematoma, improved image quality, enhanced needle tip visualization, and greater clinician satisfaction during routine care, in the mid-forearm group.[46] This newer puncture site may gradually replace the traditional volar wrist site during PAC placement in the critically ill patient.[21–24,46–48]

Regarding needle insertion, several authors have proposed an angle of needle insertion between 30° and 45°.[49,50] Low angles of insertion (15°–30°) increase the subcutaneous tract of the catheter, and this might be associated in providing additional stabilization.[22–24,49,50]

Considering the orientation of the needle, recent studies in both children and adults suggest that a "bevel-down" instead of a "bevel-up" approach may reduce insertion times and decrease the risk of posterior wall puncture, in both arterial and venous cannulation.[51,52] While many clinicians frequently utilize the "bevel-up" approach, ultrasound-guidance highlights the needle position, allowing the rotation of the cannulating needle to the "bevel-down" position prior to immediate vessel puncture. This novel approach may be associated with higher success and fewer related complications such as hematoma, reducing the difficulty in advancement of the guidewire when a Seldinger technique is utilized.[7,23,52–58]

Step 7: Assessment of catheter length

The catheter length should be determined by the selected insertion site, as the angle of insertion will influence the overall indwelling length. When a lower angle of insertion is used, a longer catheter length is required. This is frequently associated with a longer subcutaneous tract, which may provide increased device stability, improved dwell times, and risk of reduced failure, thrombosis, and infection.[23,49,50] To reduce failure after PAC placement, it is recommended that >65% of the catheter length should dwell within the lumen of the vessel.[22,23,49,50]

Step 8: Proper catheter securement

Securing PACs with sutures should be avoided, since it is frequently associated with increased local bleeding, the need for repeated dressing changes, high risk of infection, loss of established access, and needlestick injuries.[59,60] Cyanoacrylate glue provides effective securement for PAC

Table 1. The eight steps of SIA protocol.

Step 1	*Visual assessment of the skin*	Inspect insertion area for bleeding, hematoma, redness, swelling, or signs of local infection.
Step 2	*Assessment of appropriate collateral circulation*	Assessment to ensure appropriate collateral circulation evaluation (Allen's test if radial).
Step 3	*Pre-procedural ultrasound assessment*	Ultrasound allows a standardized approach for vessel assessment (state of vessel health, caliber, ratio), and an optimized choice of the insertion location, determine vessel abnormalities, visualization of surrounding anatomical structures.
Step 4	*Appropriate aseptic technique*	Hand hygiene, skin antisepsis with 2% chlorhexidine in 70% alcohol, and maximal barrier precautions.
Step 5	*Local anesthesia*	Local anesthesia in both alert and sedated patients.
Step 6	*Correct insertion technique*	Mandatory ultrasound-guided puncture and cannulation of the artery.
Step 7	*Assessment of catheter length*	Insertion of proper catheter length to ensure that at least 65% of the catheter dwell within the vessel.
Step 8	*Proper catheter securement*	Proper securement with transparent semi-permeable dressing ± cyanoacrylate glue, ±sutureless securement device.

also providing an antimicrobial and hemostatic effect at the insertion site.[23,39,59–61] The combination of a sutureless securement device, combined with cyanoacrylate glue and a transparent, semipermeable membrane dressing (with or without the additional of chlorhexidine) may significantly prevent accidental catheter dislodgement and effectively stabilize and protect the exit site (Table 1).

Conclusions

Standardization is now considered mandatory for providing quality care in vascular access, and insertion bundles are designed to facilitate effective implementation and integration of appropriate procedures into hospital policies and practices, maximizing efficiency and cost-effectiveness.[62–65] Arterial cannulation should be performed by clinicians with clearly established competencies, along with associated knowledge and skills.[8,29,66]

The strategies outlined in this bundle make sure a standardized approach is utilized, incorporating ultrasound, appropriate vessel size and catheter ratio, adequate catheter length, correct angle of insertion, and proper securement methods. These steps provide healthcare professionals with a streamlined and uncomplicated approach, extending the performance and durability of the arterial catheter, while at the same time, reducing complications.

The SIA protocol is the first ultrasound-guided arterial insertion bundle, providing a high-level, evidence-based approach to PAC placement, presenting a superior blueprint for procedural excellence. Use of the SIA protocol intends to minimize avoidable and unnecessary complications and patient injury, advancing practice while driving an optimal patient safety profile, while improving the patient and clinician experience.

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