

# ARTERIAL CANNULATION: A CRITICAL REVIEW

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*Arterial catheterization for hemodynamic monitoring is used widely in clinical management. Complications of cannulation have been recognized since introduction of the technique.*

*This review examines radial, brachial, axillary, and femoral cannulation sites. Waveform distortion, adjacent structure injury, and the incidence of thrombus are described.*

*Computerized subject heading searches were executed using CINAHL and MEDLINE databases. Searches encompassed English-language, randomized, controlled trials, reviews, practice guidelines, and meta-analyses published from January 1997 to February 2002. Additional studies*

*were identified via review of retrieved literature.*

*Radial cannulation is subject to inaccuracy and thrombus formation, although a benefit is dual circulation. The brachial site is subject to inaccuracy, lacks collateral circulation, and is associated with median nerve injury. Axillary cannulation provides data closely approximating aortic pressure and poses minimal thrombotic risk but is associated with brachial plexus compression. Femoral cannulation provides a pulse contour approximating aortic with minimal thrombotic risk. There is little evidence to show increased incidence of catheter-related systemic infection at this site.*

**Key words:** Arterial cannulation, site review.

**P**ercutaneous arterial cannulation is used widely in the clinical management of critically ill adults, with arterial circulatory invasion second in frequency only to intravenous cannulation.<sup>1</sup> Arterial monitoring allows uninterrupted display of pulse contour and continuous real-time heart rate and blood pressure measurement. The intra-arterial catheter is inserted percutaneously via a number of superficial arteries, including the radial, ulnar, brachial, axillary, and less frequently, the dorsalis pedis and temporal vessels.

Complications of arterial cannulation, including hemorrhage, infection, vascular insufficiency, ischemia, thrombosis, embolization, and neuronal or adjacent structure injury, have been recognized since introduction of the technique into practice. Such iatrogenic injuries contribute to morbidity, prolonged length of stay, financial burden, and appreciable long-term injury of medicolegal significance. A rising incidence of iatrogenic arterial injuries has been described.<sup>2</sup> Clearly, the benefit of invasive monitoring must be balanced with the associated risk.

## **Collateral circulation, ease of cannulation, and potential for neuronal or adjacent structure injury**

Surgical and anatomical considerations influence the arterial cannulation site. Unusual patient positions, the nature of the procedure, and pathophysiological disturbances influence site selection.

• *Radial artery.* The radial artery is identified superficial to the distal end of the radius between the tendons of the brachioradialis and flexor carpi radialis

and is the most frequently cannulated site for hemodynamic monitoring.<sup>1,3</sup> Extensive collateral circulation is provided via the ulnar artery and palmar arch. Although generally considered safe, reports of adverse sequelae associated with vessel occlusion exist.<sup>1,4,5</sup> Use of the modified Allen test as a predictor of ischemic complications is a matter of controversy, with a number of studies refuting predictive value.<sup>6,7</sup> Inadvertent direct neural insertion or palmar sheath blood extravasation may produce median or radial nerve pressure, with resultant carpal tunnel or sympathetic-mediated pain syndrome.<sup>1</sup>

Cannulation at this site is technically easy. In a prospective study of 536 consecutive arterial cannulations, an average radial insertion time of 2.8 minutes was described, with a 91.8% success rate of cannulation into the radial artery of choice.<sup>5</sup> Generalizability of this study may be problematic; only 13% of study participants underwent emergency cannulation. Physiologic states requiring emergency arterial access may make radial artery cannulation difficult.

• *Brachial artery.* The brachial artery, palpated at the medial side of the antecubital fossa overlying the lateral border of the brachial muscle, lacks the anatomic benefit of collateral circulation. Obstruction readily leads to diminution or obliteration of radial and ulnar perfusion. In a retrospective study of 157 patients with transbrachial hepatic artery catheters, immediate loss of the radial pulse occurred in 39.1% of brachial cannulations.<sup>8</sup> In a subsequent study, adverse sequelae were not demonstrated in more than 3,000 brachial cannulations.<sup>9</sup> Increased frequency of complications after interventional brachial catheteri-

zation have been described.<sup>10</sup> Disparity among study findings may be attributed to variables such as catheter size and pathophysiologic attributes of the study population.

A 0.2% to 1.4% incidence of median nerve injury after brachial cannulation has been described, with compression, direct nerve trauma, and ischemic occlusion resulting in appreciable long-term disability.<sup>11</sup> The safety of brachial cannulation for hemodynamic monitoring remains a clinical quandary.

- *Axillary artery.* The axillary artery is palpated in the intramuscular groove between the coracobrachial and triceps muscles, and the axillary arterial lumen is second in size to the femoral artery among peripheral vessels. Extensive collateral circulation exists to the arm, with little risk in the event of thrombosis.<sup>12,13</sup> A number of investigators have described the safety of axillary cannulation.

The axillary artery is close to the aorta; pulsation and pressure are maintained, even in the presence of vascular collapse. However, the axillary sheath encompassing the neurovascular bundle can rapidly fill with blood, and nerve damage and peripheral neuropathy may ensue secondary to compression of the brachial plexus by a hematoma. Axillary cannulation is technically difficult. A 30% rate of insertion failure among trainees and a 7% failure rate for attending staff was described in a study of 411 axillary cannulations.<sup>14</sup>

- *Femoral artery.* The femoral artery lies in a neurovascular bundle lateral to the femoral vein and median to the femoral nerve. The femoral artery is palpated midway between the anterosuperior iliac spine and the symphysis pubis. Collateral circulation exists via a number of anastomoses, and the large vessel diameter allows catheter longevity twice that of radial catheters.<sup>15</sup> Prospective and retrospective studies detail the relative safety of this site for hemodynamic monitoring.<sup>15-17</sup> A potential exists, however, for extraperitoneal hemorrhage, vascular injury from common branch entry, and cannulation hematoma. Femoral artery catheter complications, though infrequent, are more complicated, difficult to identify, and associated with significant mortality.<sup>10</sup> Soderstrom et al<sup>15</sup> described 113 femoral artery cannulations, delineating a 2.7% incidence of major complications and a 5.3% incidence of minor complications. Femoral cannulation is technically facile, and the femoral artery usually can be cannulated, even during profound shock states.

### Site-variable thrombogenicity

Thrombus formation is a formidable complication of arterial monitoring that can lead to irreversible ischemic insult. The genesis of thrombus is pre-

dictable. Homeostatic mechanisms activate as the intima is punctured. Vasospasm is directed by local and humoral responses, with resultant arterial constriction and blood flow reduction. Thrombocytes contact damaged endothelium, and platelet adhesion and aggregation begin. Intravascular velocity is altered by cannula diameter and platelet adhesion. Procoagulant factors are released by the intrinsic coagulation pathway, resulting in an insoluble clot, with diminution or obliteration of distal perfusion.

The literature consistently identifies 6 general thrombotic risk factors: larger catheter size,<sup>4,5,18</sup> hypotension,<sup>5</sup> smaller arterial dimension,<sup>4,18</sup> multiple arterial sticks,<sup>5,18</sup> duration of cannulation,<sup>4,5</sup> and administration of vasoconstrictor and inotropic agents.<sup>5,19</sup> The cannulation site further potentiates thrombotic propensity.

- *Radial artery.* A wealth of studies have examined iatrogenic thrombus formation associated with radial cannulation.<sup>2,4,6,10,17,20</sup> It generally is recognized that asymptomatic temporary occlusion occurs on radial cannulation with little consequence if adequate collateral flow is delivered via the ulnar artery. Typically, spontaneous recannulation occurs during days to weeks with no residual long-term sequelae, assuming maintenance of normotension.<sup>4,20</sup> In the largest investigation of radial cannulation, a thrombotic incidence of less than 25% was reported without occurrence of serious ischemic injury.<sup>20</sup> A 76% rate of radial occlusion without clinical signs of ischemia was described in a prospective cohort design consisting of critically ill patients.<sup>6</sup> Although the incidence of serious ischemic injury is estimated to be less than 0.01%,<sup>1</sup> the presence of varying degrees of thrombosis in up to 75% of radial cannulations demands attention. Reports of distal ischemia, digital or extremity gangrene, and clot embolization exist. Variables potentiating the risk of severe ischemic injury such as poor cardiac output and altered peripheral vascular resistance are inherent attributes in the critically ill population.

The incidence of radial artery thrombosis is correlated with vessel caliber. The radial lumen is narrow, and little increase in the external diameter of the catheter is required to evoke a significant effect on intraluminal blood flow. Radial vessels with diameters of 2.0 mm or less have a higher incidence of thrombosis than those with diameters greater than 2.25 mm; accordingly, the incidence of thrombosis is far greater in women than in men.<sup>18</sup> The interplay of vessel caliber and cannula bore has been well documented. Arteriographic, ultrasonic, and Allen test measures have demonstrated an 8% incidence of radial artery occlusion using a 20-gauge catheter and a 35% incidence in 18-gauge cannulation.<sup>4</sup> To summarize, the

percentage of intraluminal occlusion exerted by cannula size via mathematical analysis of vessel diameter and catheter size demonstrates that larger catheters occupy almost the entire lumen of smaller arteries.

- *Brachial artery.* Thrombogenicity associated with brachial cannulation has been examined. Doppler ultrasonic velocity demonstrated the incidence of thrombosis in 54 brachially cannulated patients, documenting persistent radial artery obstruction in 2 patients but no instances of significant ischemic injury.<sup>21</sup> A 1.7% incidence of thrombosis was reported in 157 percutaneous transbrachial hepatic artery catheters in an oncology sample.<sup>8</sup> Failure to use angiography at decannulation represents a design limitation, and generalizability of findings may be limited because of pathophysiological attributes of the study population (eg, neoplasm-induced procoagulant secretion, chemotherapy-induced vascular injury). Bazaral et al<sup>9</sup> described 3,000 brachial cannulations, and only 1 patient required a thrombectomy and no untoward residual effects occurred. Subsequently, thrombosis has been reported as the most common complication of brachial cannulation.<sup>2</sup>

- *Axillary artery.* The intraluminal diameter of the axillary artery decreases the likelihood of thrombus formation, and thrombosis at this site poses little threat. Multiple studies expound the safety of this site.<sup>12-14,16</sup> A low incidence of thrombosis was reported in 435 axillary cannulations, with a 1:500 incidence of serious complications.<sup>14</sup> Gurman and Kriegerman<sup>16</sup> retrospectively studied 130 axillary cannulations and found no instance of mural thrombi when angiographic instrumentation was used.

Although the incidence of thrombus at the axillary site may be less than that of smaller vessels, the threat of thromboembolization exists. Anatomically, the right axillary artery arises from the brachiocephalic trunk communicating with the common carotid artery. It is possible for cerebral thromboembolism to occur during system flushing. For this reason, cannulation of the left axillary artery may be preferred to cannulation of the right.

- *Femoral artery.* Cannulation of the femoral site permits access to a waveform closely resembling that of aortic pressure. Femoral artery occlusion secondary to thrombus is rare, owing to a greater vessel-to-catheter ratio and a higher rate of blood flow. A number of investigators describe the low incidence of thrombotic injury at this site.<sup>15-17,22</sup> In a prospective study of 113 femoral cannulations, preferential use of the femoral artery for hemodynamic monitoring was described.<sup>15</sup> Gurman and Kriegerman<sup>16</sup> used arteriographic instrumentation in a retrospective analysis

that detected only 1 clinically significant mural thrombus in 50 cannulated femoral arteries.

### **Catheter-related bloodstream infection**

Catheter-related bloodstream infection (CR-BSI) is of concern with arterial cannulation. The femoral site is the most implicated, and a number of studies examined CR-BSIs attributable to femoral cannulation. CR-BSI generally is defined as isolation of the same organism (identical species) from a semiquantitative or quantitative culture from a patient with accompanying clinical signs of bloodstream infection and no other apparent source of infection or defervescence after removal of an implicated catheter.

In a study of 113 femoral cannulations, no instance of CR-BSI was identified despite catheter duration of 3 days or more in 74 patients.<sup>15</sup> In a retrospective study of 220 femoral cannulations, Gurman and Kriegerman<sup>16</sup> described only 4 cases of a positive blood culture incriminating femoral arterial cannulation. In summary, the literature indicates that femoral artery catheters do not pose a greater risk of CR-BSI than do arterial catheters inserted in the upper extremities.<sup>15,17,22</sup>

### **Site-variable waveform distortion**

Distinction must be made between central and peripheral arterial pressure. Central pressure represents blood pressure within or in proximity to the heart. Peripheral pressure represents blood pressure obtained in smaller, distal arteries. Pathophysiologic aberration, cardiopulmonary bypass (CPB), vasoactive agents, anesthetics, and core temperature changes invoke pressure gradients that alter the relationship between central and peripheral arterial pressures. The arterial waveform at the aortic root bears little similarity to that observed peripherally, with morphologic changes occurring during vascular tree transmission. As the arterial pressure wave is conducted away from the heart, the wave narrows, the dicrotic notch becomes smaller, the systolic deflection increases, and the pulse pressure widens.

- *Radial artery.* The radial waveform is subject to inaccuracy inherent to the distal location. If the radial artery is cannulated for monitoring, the clinician must remain cognizant of distortions invoking the initiation of unnecessary therapy. Karamanoglu et al<sup>23</sup> described substantial differences in contour and amplitude of the ascending aortic pressure wave compared with radial.

Radial catheters may produce an attenuated waveform with an exaggerated pulse pressure in states of hypovolemia and vasoconstriction.<sup>14</sup> Urzua et al<sup>24</sup>

prospectively studied the effects of thermoregulatory vasoconstriction and concluded that the combination of more forceful cardiac ejection, stiffer arteries, and locally increased arteriolar resistance produced marked radial waveform distortion, artifactually increasing peak systolic pressure. By using a prospective observational design, Dorman et al<sup>3</sup> studied the adequacy of radial pressure monitoring during high-dose vasopressor administration and concluded that radial pressure underestimated central pressure and resulted in excessive vasopressor administration.

Variable aortic to radial disparity exists post-CPB, with some patients demonstrating radial artery mean pressures equal to the aortic mean and others demonstrating radial pressures as low as 65% of the aortic mean.<sup>9</sup> Van Beck et al<sup>25</sup> described systolic gradients greater than 10 mm Hg in 52% to 77% of patients post-CPB, with systolic arterial gradients of 20 to 60 mm Hg in 15% of patients. Thrush et al<sup>26</sup> prospectively studied 22 patients and described aortic and radial blood pressure disparity great enough to lead to administration of unnecessary therapy or withholding of appropriate circulatory support, with the radial mean pressure less than 55 mm Hg when aortic pressure was as much as 11 mm Hg higher. In some cases, mean radial pressure was clinically acceptable when aortic pressure indicated significant hypotension. Pauca et al<sup>27</sup> demonstrated poor radial estimates of systolic blood pressure in narcotic-anesthetized patients with known obstructive coronary artery disease.

- **Brachial artery.** The accuracy of brachial wave morphology and measurement represents an area of controversy. Bazaraal et al<sup>9</sup> studied 82 brachial cannulations and concluded that brachial pressure was more accurate than radial pressure. Van Beck et al<sup>25</sup> prospectively analyzed systolic and mean arterial pressure disparity in ascending aortic and brachial pressures post-CPB and concluded that brachial monitoring offered no advantage to radial.

- **Axillary artery.** Cannulation of the axillary artery reflects central pressure and provides more reliable waveform morphology than that of peripheral catheters. Axillary monitoring more accurately reflects systolic blood pressure, and proximity to the aortic arch affords accurate pressure and waveform, even during profound vasoconstriction. Axillary cannulation may be used during extended monitoring, owing to a large intraluminal bore. Van Beck et al<sup>25</sup> concluded that the axillary artery was the most distal site in the upper extremity at which arterial pressure consistently and accurately estimated central aortic pressure post-CPB.

- **Femoral artery.** Femoral cannulation affords access to central pressure, a morphologically reliable waveform, and an accurate reflection of systolic blood

pressure. Femoral catheters provide an accurate estimation of central pressure in hypovolemic, vasoconstricted, and central shunting states, with waveform changes less than those observed in the radial artery during vasoconstriction.<sup>24</sup> Femoral systolic pressure exceeding radial systolic pressure by more than 50 mm Hg has been described.<sup>3</sup> As with axillary cannulation, the large intravascular lumen of the femoral artery allows extended monitoring.

## Conclusion

Arterial cannulation provides uninterrupted display of pulse contour and continuous beat-to-beat hemodynamic measurement. Such data are invaluable for effective clinical management. Arterial invasion is not without risk, and the prudent clinician must weigh the risk-to-benefit ratio. Iatrogenic injuries contribute to morbidity, prolonged length of stay, financial excess, and appreciable long-term injury of medicolegal significance.

Site selection must consider clinician cannulation skill, patient positioning, pathophysiologic attributes, the potential for neuronal or adjacent structure injury, and thrombotic propensity (Table). Central and peripheral pressure measurement disparity must be considered during the course of inotropic or vasoactive support. Each arterial cannulation site has distinct advantages and disadvantages that should be considered by the prudent clinician.

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**Table. Comparative analysis of arterial cannulation sites**

	<b>Brachial</b>	<b>Radial</b>	<b>Axillary</b>	<b>Femoral</b>
<b>Ease of cannulation</b>	No data obtained	Less difficult in normotension, although hypotension and vasoconstriction may render cannulation difficult	Technically difficult, although pulsation and pressure are maintained even with peripheral vascular collapse	Less difficult, can be cannulated, even during profound hypotension
<b>Collateral circulation</b>	Lacks the anatomic benefit of collateral circulation	Dual circulation in most of the population	Extensive collateral circulation	Collateral circulation exists via a number of anastomoses
<b>Inadvertent neural or adjacent structure injury</b>	Damage to the median nerve may result in appreciable long-term disability	Carpal tunnel or sympathetic-mediated pain syndrome from median or radial nerve pressure or from blood extravasation into palmar sheath	Axillary sheath rapidly fills with blood; nerve damage and neuropathy secondary to brachial plexus compression	Potential for extraperitoneal hemorrhage from too high an entry site; vascular injury from femoral common branch entry; hematoma formation
<b>Thrombogenicity</b>	High risk; thrombotic sequelae may be profound	High risk, smaller arterial lumen associated with increased risk of thrombosis	Less risk; catheter at this site poses little risk if thrombosis occurs	Less risk; large intraluminal diameter and high rate of flow discourage thrombus formation
<b>Accuracy of waveform</b>	Substantial difference in contour and amplitude of ascending aortic and brachial waveform	Substantial difference in contour and amplitude of ascending aortic and radial waveforms	Proximity to aortic arch allows a reliable waveform, even during profound vasoconstriction	Morphologically reliable waveform
<b>Accuracy of physiological data</b>	Subject to inaccuracy inherent in distal location; overestimates systolic blood pressure; may be more accurate than radial approach	Subject to inaccuracy inherent in distal location; overestimates systolic blood pressure; underestimates central aortic pressure	More accurately reflects systolic blood pressure	More accurately reflects systolic blood pressure

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