Neurovascular Complications of the Upper Extremity Following Cardiovascular Procedures

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Abstract

Background Cardiovascular procedures are common and are trending toward endovascular interventions. With this increase in endovascular procedures, there is also increasing awareness of upper extremity morbidity resulting from treatment.

Methods Articles indexed within PubMed between the years 1975 and 2015 that discussed such complications were reviewed.

Results Percutaneous radial artery access can lead to nerve ischemia, especially in the setting of an incomplete arterial arch, whereas radial artery harvesting for bypass surgery more commonly causes frank tissue ischemia and radial neuropathy. Transulnar catheterization may cause ischemic hand injuries, while transbrachial angiography has resulted in compartment syndrome. Injuries to the nerves themselves often result from surgical equipment, such as sternal retractors, or from patient positioning leading to compression of the ulnar nerve. For percutaneous radial artery access, the incidence of ischemic injury is as high as 24%, whereas nerve injury is too rare to be estimated. In the setting of radial artery harvesting, ischemic injury is limited to case reports, and radial neuropathy is estimated to occur in as many as 25% of patients at discharge. Open heart surgery is the primary setting in which equipment or patient positioning plays a role, affecting 10% of patients with brachial plexus injuries and 15% with ulnar neuropathies.

Conclusion Complications following cardiovascular interventions are varied and are typically associated with specific procedures. Careful preoperative and postoperative assessments of patients may aid in preventing, minimizing, and treating these often undiagnosed complications.

Keywords
- upper extremity
- hand
- cardiovascular
- procedures
- complications

Introduction

The global burden of cardiovascular disease is expanding, accounting for 17.3 million deaths per year worldwide. Many procedures, such as coronary artery bypass grafting with vascular harvesting, are well-established methods of treating cardiovascular disease.[1] To further combat this pathology, however, the cardiovascular device market is growing. The development, and increasing use, of percutaneous devices necessitating stable vascular access has prompted a trend toward endovascular interventions.[2] With this rise, there is also an increasing awareness of upper extremity morbidity resulting from treatment.[3]

While prior studies have reported and evaluated discrete neurovascular injuries following cardiovascular procedures, to the authors' knowledge, no reviews on the topic exist.[4–6] Consequently, the aim of this review is to provide an overview of hand and upper extremity complications after cardiovascular procedures, which, given the dearth of literature, appear to be both underaddressed and, in many cases,

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underappreciated, by orthopedic, cardiothoracic, and vascular surgeons.

Methods

A comprehensive PubMed search was performed to achieve the aforementioned aim. The keywords and phrases used in the search included "upper extremity," "cardiovascular procedure," "catheterization," "artery harvest," and "complication." Original studies, review articles, and case reports that were published between the years 1975 and 2015 and discussed upper limb complications associated with cardiovascular procedures were included in this review.

Results

Mechanisms of Injury and Epidemiology

In the setting of cardiovascular procedures, injury to the hand and upper extremity results primarily from neurovascular damage. The patterns of injury are often associated with specific interventions, as outlined in ►**Fig. 1**.

Radial Artery Harvesting

Although initially criticized for inadequate results during its early use, the radial artery has become an increasingly popular vascular conduit for coronary artery bypass grafting over the past few decades, currently used in approximately 10% of such procedures and steadily increasing (though internal mammary artery harvest remains more common).[7–9] Postoperatively, the more common complications following radial artery harvesting are neurologic in nature. These are often due to thermal injuries to adjacent sensory/motor fibers, traction of the distal/peripheral aspect of the nerve, or devascularization, resulting in radial or median neuropathy or frank tissue ischemia of the hand. To characterize these complications, Meharwal and Trehan[8] conducted a prospective analysis of 4,172 anastomoses with the radial artery. In evaluating the functional status of the hand following harvest, the authors found that 25% of patients experienced numbness and paresthesias in the radial nerve distribution, while 2% endorsed some limitation of hand activity at the time of discharge from the hospital. In 6.5% and 3% of patients, respectively, numbness and paresthesias persisted beyond 3 months. Additionally, 1.6% of patients experienced loss of sensation in the lateral antebrachial cutaneous nerve distribution. Allen et al[3] in their retrospective study of 288 patients undergoing coronary artery bypass grafting with the radial artery reported the incidence of radial sensory neuropathy to be 9.9%. Comparing the patients with a control cohort, the authors found that those undergoing radial artery harvest had significantly lower Disabilities of the Arm, Shoulder, and Hand (DASH) scores compared with those without harvest, suggesting a greater degree of postoperative hand impairment. To better stratify these complications, Moon[4] et al compared the results of conventional cold scalpel versus harmonic scalpel techniques for radial artery harvest. In their study, complications and symptoms were defined as thumb numbness or weakness, tingling, or pain within the hand. They found a similar, but significant, number of neurologic hand complications with the two techniques. More specifically, 11.2% of patients in the cold scalpel group and 11% in the harmonic scalpel cohort experienced one or more of the aforementioned symptoms; 19% of these completely resolved within 1 year, while symptoms persisted long term in 9% of patients. In addition to neuropathy, while largely limited to case reports, tissue ischemia has also been reported.[10,11] Despite adequate ulnar compensatory circulation, harvest of the radial artery has been shown to induce a degree of hand ischemia as measured by transcutaneous oximetry, most notably under exercise conditions.[12]

Percutaneous Vascular Access

The use of percutaneous coronary interventions has increased both within the United States and abroad over the past several years as advancements in endovascular technology have begun to meet clinical demand. Paralleling this increased use, however, has been a growing concern regarding the potential complications of these procedures.

Transradial cardiac catheterization has been heralded as a clinically superior alternative to the more traditional transfemoral approach, as it is associated with a lower rate of access site related complications.[13] Nonetheless, percutaneous radial artery access can lead to ischemia in the setting of coronary interventions, especially in the setting of an incomplete arterial arch,

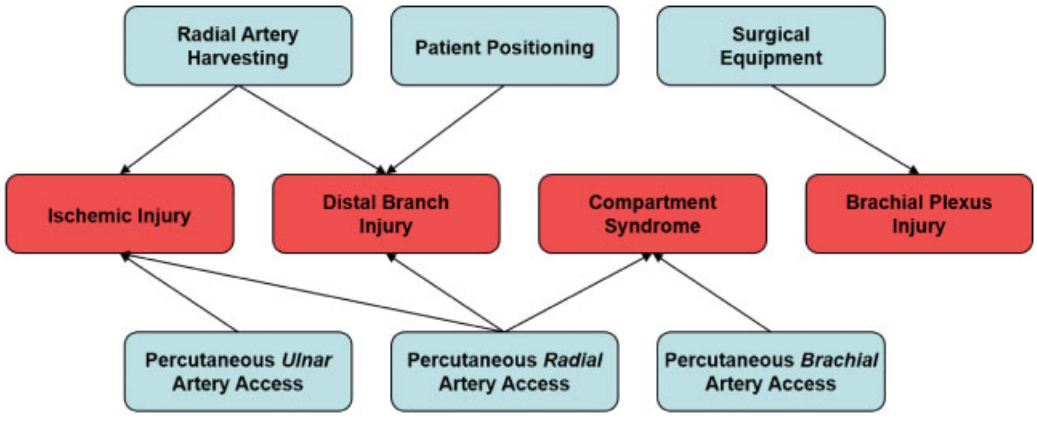

Fig. 1 Schematic of various cardiovascular procedures and their corresponding upper extremity complications.

nerve injury, and (rarely) compartment syndrome. Occlusion may result from local arterial injury and constriction at the time of decannulation, which may stimulate thrombus formation. Additionally, studies using histological analysis, ultrasound, and optical coherence tomography have demonstrated that catheterization can lead to endothelial damage via denudation and dissection.[14] This, in turn, may cause significant endothelial cell dysfunction, thereby inducing intimal hyperplasia and, potentially, occlusion. Kanei et al[13] estimated the prevalence of radial artery occlusion following catheterization to be between 2 and 18%, the risk factors for which are repeated entry attempts, prolonged high pressure compression, and a low artery-to-sheath ratio. They estimated the rate of radial artery vasospasm to be between 5 and 10%, predominantly seen in female patients and patients with smaller radial arteries. Stella et al[15] reported that 5.3% of patients had clinical evidence of radial artery occlusion while in the hospital following transradial angioplasty, and 2.8% of patients had this persist beyond 1 month after discharge. Critical hand ischemia following cannulation is a rare occurrence. Believed to be due to digital embolization of a radial artery thrombus or in situ thrombus formation within collateral vessels, it is thought to occur in 0.09% of cases; however, the true incidence is unknown as it is only described in case reports.[16,17] Similarly, nerve injury following radial artery catheterization is rare, often attributable to repeated punctures that pierce the radial or median nerves. While typically self-limiting, these injuries could lead to pain, swelling, and range of motion limitations consistent with complex regional pain syndrome.[13] Additionally, perforation of the radial artery occurs in up to 1% of cases due to aggressive wire manipulation. Particularly in the anticoagulated patient, this may lead to hematoma formation, which can evolve into forearm compartment syndrome in an estimated 0.004% of cases.[13] While extremely rare, the potentially devastating consequences of compartment syndrome cannot be overstated. To assess for a change in general upper extremity function, van Leeuwen et al[18] analyzed 338 patients who underwent coronary catheterization via the transradial or transfemoral approach. They found that upper limb function, based upon DASH scores and the Cold Intolerance Symptom Severity questionnaire, was not negatively affected by transradial interventions. Zwaan et al[19] conducted an extensive review of 176 articles regarding transradial percutaneous access and found the overall incidence of access-site complications to be 9.6%. Upper limb dysfunction was noted in 1.7% of patients, but the authors stated that few studies actually investigated dysfunction, and many of those that did, lacked a robust assessment. Consequently, the authors claimed that upper extremity dysfunction following radial artery catheterization is likely underestimated in the literature.

Similar to percutaneous radial artery access, transulnar catheterization may lead to ischemic hand injuries. Knebel et al[6] in their cohort study of 26 patients who underwent cardiac catheterization via the transulnar approach noted that 4% of patients sustained an ulnar artery injury that required urgent revascularization. While no ulnar nerve injuries were reported, the authors stated that the risk of such injury is possible and was likely limited by the use of a carefully placed small-gauge needle during their catheterization procedures. An extensive review by Sattur et al[20] further classified ulnar artery injuries, citing an incidence of 0.8% for large hematoma formation and 2.4% for local hematomas. Additionally, they found that ulnar artery occlusion occurs in 1.9% of patients, while pseudoaneurysm formation is evident in 0.08% of cases.

The transbrachial approach for catheterization has also been promoted as an alternative to transradial and transulnar access, although its use is very limited compared with the transradial approach. As with the aforementioned approaches, transbrachial angioplasty is not without its potential complications. Omori et al[21] published a case series of patients who developed compartment syndrome following brachial artery transcatheter angiography necessitating urgent fasciotomy. The authors attributed several factors, including the large sheath size necessary to cannulate larger arteries, to the development of compartment syndrome in these cases.

Surgical Equipment

In addition to the approach (e.g., transradial) for obtaining vascular access, the surgical equipment utilized in cardiovascular procedures has also been shown to cause neurologic complications. Within the extant literature, perhaps the most commonly discussed association is between the use of sternal retractors and brachial plexus injuries. During a median sternotomy, fully opened sternal retractors push the clavicles into the retroclavicular spaces, while the first ribs are rotated superiorly, thereby increasing the tension on the brachial plexus.[22] Direct needle trauma during catheterization of the internal jugular vein may also contribute to brachial plexopathy. Healey et al[22] in their review of 12 studies concluded that the incidence of brachial plexus injury following median sternotomy is as high as 37.7%. Other studies have estimated a lower incidence of 5.5 to 10%.[23] Such a discrepancy may be due to the use of different retractor sizes between the studies. To further stratify these patients, Canbaz et al[24] demonstrated that 14% of patients undergoing coronary artery bypass and 8% of patients following open valve surgery had evidence of a brachial plexus injury. These rates may be higher in older patients, in the setting of longer operative times, and with internal mammary artery harvesting due to asymmetric retraction of the sternal halves. The predominant symptoms stemming from brachial plexus injuries in these settings include continuous upper extremity pain, as well as various motor and sensory disturbances, which more commonly affect the left upper extremity.[25] Such symptoms often resolve within 6 months, but occasionally may persist for extended periods of time.[26]

Patient Positioning

The position of the patient during cardiac surgery, specifically through hyperabduction of the upper extremity, may also lead to nerve injury. Watson et al[1] performed electrophysiologic studies both preoperatively and at various postoperative intervals in a prospective series of patients who underwent coronary artery bypass grafting. They identified a 15% overall incidence of compressive ulnar neuropathies, with conduction velocities across the elbow reduced in 8% of cases,

Table 1 Preoperative testing to prevent complications following radial artery harvest

Preoperative testing	Test/intervention
Clinical	Allen's test Doppler examination Pulse oximetry
Advanced	^{99m}Tc-HSA

Abbreviation: Tc-HSA, technetium-human serum albumin.

denervation in 10%, and conduction block and intrinsic weakness in 5% of patients. Seyfer et al[27] reported a notably higher rate of ulnar neuropathy (38%) in their series of 53 patients. The mean duration of symptoms was 2.3 months, but some patients had symptoms lasting for over 6 months.

Prevention and Management

While most upper extremity injuries will resolve spontaneously, with estimates as high as 90% resolution at 1 year follow-up, appropriate action should be taken to both prevent (when possible) and manage these complications.[4]

In the setting of planned radial artery harvesting, a thorough preoperative evaluation should be performed to assess the adequacy of collateral circulation within the hand (►**Table 1**).[8] Such an assessment may include the Allen's test, Doppler examination, and, in certain cases, pulse oximetry. Additionally, some clinicians espouse the use of more advanced preoperative testing. Specifically, Garai et al[28] recommend performing hand perfusion studies with the injection of technetium 99-m labeled human serum albumin in patients with an abnormal Allen's test to identify those who are truly at an increased risk of hand ischemia following radial artery harvest for coronary artery bypass grafting. An abnormal Allen's test is often defined as the inability of the hand to flush within 15 seconds after releasing occlusive pressure on the ulnar artery. They advocate for the routine preoperative use of this test as a noninvasive screening tool to assess hand circulation.

The upper extremity morbidity associated with percutaneous coronary interventions can be managed through a variety of approaches (►**Table 2**). The use of smaller catheterization equipment, such as a 5 French or less guiding catheter, through a slender percutaneous technique may aid in decreasing the rate of vascular damage.[29] If clinical symptoms are minimal but there is concern for vascular damage following catheterization, pulse wave analysis, in concert with provocative albuterol testing, can be performed to noninvasively assess endothelial function in vivo.[30] Arterial occlusion following transvascular catheterization should be addressed with the administration of anticoagulation and patent hemostasis.[13] Vascular perforation leading to hematoma formation, and potentially compartment syndrome, should be detected early and a compressive bandage be applied to the extremity. If compartment syndrome develops, emergent fasciotomy should be performed. Moreover, while no clear consensus exists regarding the ideal treatment approach for hand ischemia, early identification, as evidenced by an absent pulse, pallor, or cold fingers, is critical. The intra-arterial injections of prilocaine, verapamil, phentolamine, and urokinase have been effective in reversing ischemia.[16] Furthermore, aspiration of thrombus at the tip of the catheter has been shown to restore vascular pulsation in upward of 60% of patients with a presumed thrombosis. In cases refractory to these measures, techniques such as retrograde subintimal recanalization as well as excision of the thrombosed segment with reconstruction with vein-graft interposition or thrombectomy with patch angioplasty have been reported with varying degrees of success.[31–33]

In addition to meticulous dissection and catheter placement, appropriate use of surgical equipment and careful patient positioning may minimize the incidence of brachial plexopathy and compressive ulnar neuropathy (►**Table 3**). Notably, caudal placement of a symmetrical sternal retractor, as well as removal of the upper retractor blades, relieves pressure on the superior neurovascular structures and has been shown to reduce brachial plexus injuries.[22] Also, patient positioning using the "hands up" technique, whereby the patient's arms are elevated above the level of the operative table and behind the head, reduces the incidence of brachial plexopathy and compressive ulnar neuropathy when compared with patients whose arms are left at the side during open cardiovascular procedures.[25]

Table 2 Management of transvascular catheterization complications

Type of complication	Management strategy
Arterial occlusion	Anticoagulation Patent hemostasis
Compartment syndrome	Compressive bandage (hematoma) Emergent fasciotomy
Hand ischemia	Intra-arterial injection Aspiration of thrombus

Conclusion

Upper extremity complications following cardiovascular procedures are varied in nature and are typically associated with specific interventions. Radial artery harvesting may lead to neuropathy or ischemic injuries to the hand, while percutaneous angiography or angioplasty can cause similar

Table 3 Prevention of brachial plexopathy and ulnar neuropathies during open cardiovascular procedures

Intraoperative factor	Method
Surgical equipment	Caudal placement of symmetrical retractor Removal of upper retractor blade
Patient positioning	"Hands up" technique

complications in addition to compartment syndrome, in rare cases. The use of sternal retractors and other surgical equipment during open cardiac procedures may result in brachial plexopathies, while patient positioning has been shown to contribute to ulnar neuropathy. Careful preoperative and postoperative evaluations of patients may aid in preventing, minimizing, and treating these often undiagnosed complications.

Conflict of Interest
None.

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