Although transradial arterial access (TRA) has demonstrated a lower incidence of bleeding and vascular complications compared to femoral and brachial arterial access, complications after TRA nonetheless occur.\textsuperscript{1-10} One complication unique to this approach is the forearm hematoma. Because there are no large multicenter registries examining forearm hematomas as a complication of TRA, it is difficult to ascertain their exact incidence. Single-center experiences report major hematomas occurring in 0.4\% to 0.73\% of cases and minor hematomas or bruising in up to 6\%.\textsuperscript{11-16} It should be pointed out that these studies lack precise definitions of hematoma, include a highly variable patient population, and utilize different levels of anticoagulation.

Variables related to the development of a forearm hematoma can be separated into clinical, anatomic, and technical (Table 1). Clinical features such as advanced age, female gender, and diabetes are generally associated with vascular and bleeding complications.\textsuperscript{17,18} Large sheath-to-radial artery size ratio, spasm, atherosclerotic disease, tortuosity, and congenital anatomic variations (radial "loop," accessory or early take of radial artery, etc.) are more specifically associated with increased TRA complications.\textsuperscript{19-22} As with any vascular/bleeding complication, aggressive anticoagulant and antiplatelet therapy will also predispose to hematoma formation in the forearm.\textsuperscript{22}

**POTENTIAL MECHANISMS**

There are at least three potential mechanisms for the development of a forearm hematoma. These can be separated into (1) persistent bleeding from the access site, (2) perforation of the radial artery, and (3) perforation of a radial artery side branch.

Persistent bleeding from the access site generally occurs only after removal of the arterial sheath. Bleeding around the sheath is rarely seen but can occur after difficult arterial access, excessive anticoagulation, or exchange for a smaller sheath. In the scenario of access site bleeding, subcutaneous blood travels proximally creating a forearm hematoma. Recognition of access site bleeding is usually obvious. The treatment is to effect hemostasis at the arteriotomy site, either through manual or device compression. Reversal of anticoagulation and occlusive hemostasis is an option in extreme cases but is associated with higher rates of radial artery occlusion.

Perforation of the radial artery can occur during sheath or catheter insertion and is related to large sheath/artery size ratios ($>1$) or any other impedance to sheath/catheter entry. Examples include (1) spasm of the radial artery, which effects a dynamic change in the catheter/artery ratio; (2) excessive tortuosity of the radial artery; (3) congenital anatomic variations often introduce significant
resistance to the advancement of catheters through the radial artery, increasing the likelihood of trauma; and (4) focal atherosclerotic disease. Resistance to sheath/catheter advancement is an indication that one of these conditions may be present and should be a signal for the operator to stop and further evaluate the artery. Angiography with diluted contrast through a small dilator, the sheath sidearm, or the distal end of a catheter will identify the cause of resistance.

Unlike the femoral artery, the radial artery has many small side branches. A wire aggressively advanced into a side branch can result in perforation. This would seem to be a rare event but may be more common with hydrophilic wires.23-25 If the origin of a small perforated side branch is occluded by a sheath or catheter during the course of the procedure, bleeding will be limited and likely of little clinical consequence. Spasm and thrombosis within these small branches generally provides permanent hemostasis after sheath removal. The clinical consequences may be more significant if the side branch is large, anticoagulation is aggressive, or tearing of the side branch leads to perforation (due to advancement of the sheath of catheter into the side branch over the wire).

Bertrand et al have graded forearm hematomas according to their size, which has implications regarding the severity of their potential clinical consequences (Table 2). This scale includes a hematoma < 5 cm (grade I), < 10 cm (grade II), distal to the elbow (grade III), and proximal to the elbow (grade IV). Hematomas grade III and IV are not directly related to the puncture site but result from wire damage to vessels and small perforations.22,26

**TABLE 1. VARIABLES LIKELY ASSOCIATED WITH DEVELOPMENT OF A FOREARM HEMATOMA WITH TRANSRADIAL ARTERIAL ACCESS**

<table>
<thead>
<tr>
<th>Clinical</th>
<th>Anatomic</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Previous TRA complication</td>
<td>• Spasm</td>
<td>• Large sheath/artery size</td>
</tr>
<tr>
<td>• Female gender</td>
<td>• Anatomic variations</td>
<td>• Sheath exchange</td>
</tr>
<tr>
<td>• Advanced age</td>
<td>• Radial atherosclerotic disease</td>
<td>• Hydrophilic wires</td>
</tr>
<tr>
<td>• Diabetes</td>
<td></td>
<td>• Excessive anticoagulation</td>
</tr>
</tbody>
</table>

**TABLE 2. RADIAL ARTERY HEMATOMA CLASSIFICATION**

<table>
<thead>
<tr>
<th>Grade I</th>
<th>Grade II</th>
<th>Grade III</th>
<th>Grade IV</th>
<th>Grade V</th>
</tr>
</thead>
<tbody>
<tr>
<td>• &lt; 5 cm</td>
<td>• 5–10 cm</td>
<td>• &gt; 10 cm</td>
<td>• Proximal to elbow</td>
<td>• Compartment syndrome</td>
</tr>
<tr>
<td>• Access site related (distal to elbow)</td>
<td>• Access site related (distal to elbow)</td>
<td>• Access site related (distal to elbow)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MANAGEMENT**

As with any complication, prevention of a forearm hematoma is preferred to treatment. Before the procedure, consideration of radial artery size and any previous radial complication are important factors in discerning preprocedure risk. During the procedure, any resistance to sheath/catheter advancement should prompt angiographic evaluation to determine the location and mechanism of resistance. Treatment of spasm or atherosclerotic...
disease, selection of alternative equipment, or re-evaluation of access approach can then be appropriately implemented. Interestingly, in the case of radial artery perforation, the best treatment may be to continue the case. We have found that if a catheter can traverse and then tamponade the area of concern, the perforation will often seal by the conclusion of the case (Figure 1). After sheath removal, small nongrowing hematomas in the forearm can generally be managed conservatively. A loose compression dressing, gentle elevation of the arm, and careful observation may suffice. The use of cold compresses or ice packs is controversial because the reduction in swelling is counterbalanced by resulting vasospasm, which may enhance radial artery occlusion or ischemia. Larger or growing hematomas require immediate attention because there is concern for compartment syndrome. Immediate control of bleeding is critical. Manual compression along the forearm is usually insufficient. It may be useful to apply a blood pressure cuff with a sphygmomanometer to the forearm for precise adjustment and gradual release of compressive pressure (Figure 2). Alternatively, a pressure dressing wrapped around the forearm can be applied. Compartment syndrome after TRA has been reported with an incidence of 0.4% or less and may result in neurologic injury, disability, or tissue loss. Causes of compartment syndrome include failed access site hemostasis, arterial laceration, or wire perforation of the artery or a side branch.25,27,28 Consequently, anticoagulation should be stopped or reversed. Further measures include control of hypertension, pain management, and close monitoring of the distal perfusion bed with plethysmography. If compartment syndrome is a concern, timely consultation with a vascular surgeon is also important in the event that surgical decompression is required.

CONCLUSION
Forearm hematomas are a unique complication of TRA. Preprocedural assessment and proper management of intraprocedural events, such as resistance to catheter advancement, may help reduce their occurrence. Small hematomas are generally easy to manage and are of little clinical consequence. Although rare, large hematomas may lead to compartment syndrome, which is a medical emergency and demands immediate attention.

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