Intraosseous Versus Intravenous Vascular Access During Out-of-Hospital Cardiac Arrest: A Randomized Controlled Trial

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Study objective: Intraosseous needle insertion during out-of-hospital cardiac arrest is rapidly replacing peripheral intravenous routes in the out-of-hospital setting. However, there are few data directly comparing the effectiveness of intraosseous needle insertions with peripheral intravenous insertions during out-of-hospital cardiac arrest. The objective of this study is to determine whether there is a difference in the frequency of first-attempt success between humeral intraosseous, tibial intraosseous, and peripheral intravenous insertions during out-of-hospital cardiac arrest.

Methods: This was a randomized trial of adult patients experiencing a nontraumatic out-of-hospital cardiac arrest in which resuscitation efforts were initiated. Patients were randomized to one of 3 routes of vascular access: tibial intraosseous, humeral intraosseous, or peripheral intravenous. Paramedics received intensive training and exposure to all 3 methods before study initiation. The primary outcome was first-attempt success, defined as secure needle position in the marrow cavity or a peripheral vein, with normal fluid flow. Needle dislodgement during resuscitation was coded as a failure to maintain vascular access.

Results: There were 182 patients enrolled, with 64 (35%) assigned to tibial intraosseous, 51 (28%) humeral intraosseous, and 67 (37%) peripheral intravenous access. Demographic characteristics were similar among patients in the 3 study arms. There were 130 (71%) patients who experienced initial vascular access success, with 17 (9%) needles becoming dislodged, for an overall frequency of first-attempt success of 113 (62%). Individuals randomized to tibial intraosseous access were more likely to experience a successful first attempt at vascular access (91%; 95% confidence interval [CI] 83% to 98%) compared with either humeral intraosseous access (51%; 95% CI 37% to 65%) or peripheral intravenous access (43%; 95% CI 31% to 55%) groups. Time to initial success was significantly shorter for individuals assigned to the tibial intraosseous access group (4.6 minutes; interquartile range 3.6 to 6.2 minutes) compared with those assigned to the humeral intraosseous access group (7.0 minutes; interquartile range 3.9 to 10.0 minutes), and neither time was significantly different from that of the peripheral intravenous access group (5.8 minutes; interquartile range 4.1 to 8.0 minutes).

Conclusion: Tibial intraosseous access was found to have the highest first-attempt success for vascular access and the most rapid time to vascular access during out-of-hospital cardiac arrest compared with peripheral intravenous and humeral intraosseous access. [Ann Emerg Med. 2011;58:509-516.]

Please see page 510 for the Editor’s Capsule Summary of this article.

INTRODUCTION

Background

Intraosseous needle insertion in the out-of-hospital setting is no longer exclusive to the pediatric population. Recent studies have demonstrated that intraosseous needles can be a rapid method for obtaining vascular access in adult populations, particularly in the presence of failed peripheral intravenous line placement. As a result, intraosseous needle insertion is commonly used in the out-of-hospital setting when immediate vascular access is required during out-of-hospital cardiac arrest.

Across the United States, emergency medical services (EMS) systems have amended out-of-hospital protocols to include intraosseous needle insertions for both pediatric and...
Editor’s Capsule Summary

What is already known on this topic
According primarily to observational research, intraosseous needle insertion for out-of-hospital vascular access is now in common use for children and adults.

What question this study addressed
This randomized trial assessed the proportion or first-attempt successes and procedural time in the insertion of humeral intraosseous, tibial intraosseous, and standard peripheral intravenous lines in patients with out-of-hospital cardiac arrest.

What this study adds to our knowledge
In this study of 113 paramedics treating 182 patients, tibial intraosseous placement had the highest success rate and fastest time to access, though peripheral intravenous access was associated with a larger infused fluid volume.

How this is relevant to clinical practice
For cardiac arrest or unconscious patients who require immediate vascular access but are unlikely to require large-volume fluid resuscitation, tibial intraosseous needle placement is advantageous.

Vascular Access During Out-of-Hospital Cardiac Arrest

Several animal locations (sternal, humeral, and tibial) are available for intraosseous needle insertions, but their actual effectiveness during out-of-hospital cardiac arrest is unknown. The sternal location can prove difficult in out-of-hospital cardiac arrest because of ongoing chest compressions; both the proximal humerus and proximal tibia have been identified as safe locations in the out-of-hospital setting.5,9,10

There are limited data directly comparing the effectiveness of the humeral and tibial access sites during cardiac arrest. There is also a paucity of literature demonstrating that intraosseous access is more effective than peripheral intravenous access in the out-of-hospital cardiac arrest setting. Much of the research conducted in regard to intraosseous insertion has been observational and retrospective; currently, there are no known randomized controlled trials assessing the effectiveness of intraosseous vascular access sites.

Several studies, both animal and human, illustrate how quickly intraosseous needles can be inserted. Additionally, peripheral serum drug concentrations for medications administered through intraosseous sites were proven to be equivalent to those administered through peripheral intravenous lines.11-13 However, these studies were primarily conducted in controlled environments among sedated animals, humans with topical anesthesia, or human cadavers.14,15 Furthermore, there are still concerns about discrepancies in the volume of fluid that can be administered between intraosseous sites and peripheral intravenous sites.16

Goals of This Investigation
In 2009, we conducted an observational study that found the tibial intraosseous placement to have a higher frequency of first-attempt success (80%) compared with the humeral intraosseous placement (40%) during out-of-hospital cardiac arrest.17 This represents a significant clinical difference when the delays to patient care that may occur as a result of failed vascular access in the out-of-hospital setting are considered. The objective of the current study was to assess the frequency of first-attempt success between the humeral intraosseous, tibial intraosseous, and peripheral intravenous routes during out-of-hospital cardiac arrest. It was hypothesized that a significant difference in the frequency of first-attempt success existed between tibial intraosseous needle insertions compared with humeral intraosseous needle insertions or peripheral intravenous access among patients experiencing out-of-hospital cardiac arrest.

MATERIALS AND METHODS
Study Design and Setting
This study was a prospective, nonblinded, triple-arm, randomized controlled trial. The study was conducted by the Mecklenburg Emergency Medical Services Agency (Medic). Medic is a municipal all–advanced life support EMS agency with a coverage area of more than 500 square miles, serving a population of approximately 867,000 individuals. During the study period, annualized call volume was approximately 98,000, resulting in approximately 70,000 yearly patient transports. Patients were transported to any of the 7 area hospitals, inclusive of a single academic institution and a separate regional tertiary care facility. All ambulances are staffed with at least 1 paramedic and 1 emergency medical technician (EMT)–basic. All paramedics reported to a centralized headquarters at the beginning and end of shift and were dynamically deployed throughout the county during their shift. First responders within the city and county are trained at the EMT–basic level and have access to an automated external defibrillator. Out-of-hospital triage, treatment, and transport protocols are uniform within both the county and city limits for both Medic and all first-responder agencies.

This study was approved by the Carolinas Medical Center institutional review board. Because of the urgent nature of the condition under study, out-of-hospital cardiac arrest, a waiver of informed consent was asked for and granted by the institutional review board. This study follows the CONSORT recommendations about the reporting of randomized controlled trials and was registered with ClinicalTrials.gov (NCT01119807).
Selection of Participants

This study enrolled all patients experiencing an out-of-hospital cardiac arrest from May 3, 2010, to October 23, 2010. Only adult patients older than 18 years and experiencing cardiac arrest of a medical cause were included in this study. Traumatic arrests (motor vehicle crash, penetrating injury, drowning, etc) were excluded because different out-of-hospital protocols exist for these resuscitations. Other patients excluded from this study were those with established peripheral vascular access before cardiac arrest, those with successful resuscitation before attempted initial vascular access, those in whom resuscitative efforts were halted after presentation of a do-not-resuscitate order, or those with a contraindication for the use of any of the vascular access methods. The contraindications to intraosseous use include extremity amputations, orthopedic hardware, traumatic injuries, or evidence of active infection as determined by the paramedic.

Interventions

All patients eligible for inclusion in this study had their first attempt at vascular access randomized to one of 3 locations: proximal tibial intraosseous, proximal humeral intraosseous, or peripheral intravenous. The proximal tibial insertion site was located medial to the tibial tuberosity, or just below the patella along the flat aspect of the tibia. The proximal humerus insertion site was defined as the greater tubercle of the anterior humeral head 1 cm proximal to the surgical neck of the humerus. Peripheral intravenous catheter placement could occur at any accessible peripheral vein but preferably at the antecubital fossa; the external jugular vein was not an option provided for catheterization.

To prevent delays in care during out-of-hospital cardiac arrest resuscitation, randomized note cards were distributed to paramedics at the beginning of each shift, indicating which vascular access site was to be used initially if they responded to an out-of-hospital cardiac arrest during their shift. There were 300 study note cards prepared in advance (100 each of tibial intraosseous, humeral intraosseous, and peripheral intravenous), randomly numbered and placed at the logistics window, where equipment is checked out by paramedics at the start of their shift. Logistics personnel selected the first and then sequential study cards to be distributed to the paramedic, along with the daily equipment and resuscitation pack for each ambulance. The vascular access route assigned applied only to the crew’s first cardiac arrest of the day. If a crew responded to a second cardiac arrest in a shift, they were to follow local protocol about vascular access, and that patient was not eligible for study inclusion.

On arrival to the scene of an out-of-hospital cardiac arrest, paramedics determined whether the patient was eligible to be enrolled in the study and obtained vascular access according to the assigned location on the study note card. If initial vascular access was not successful, the paramedics used their own judgment for choosing the subsequent site. Before implementation of this study protocol, all paramedics were trained on intraosseous needle insertions with the EZ-IO Power Driver (Vidacare, San Antonio, TX), an intraosseous drill insertion device, during a human cadaver laboratory. Paramedics were required to demonstrate proficiency on both humeral and tibial intraosseous needle insertions before course completion.

At the end of each shift, paramedics turned in their study card to the on-duty operations assistant and completed a performance survey if they enrolled a patient in the study. These cards were permanently removed from circulation and filed in a study folder. Those study cards not used for a cardiac arrest were signed in at the logistics distribution window and placed back into general circulation.

Outcome Measures

The primary outcome measure was first-attempt success at the assigned method of vascular access, defined as initial success and overall success. Initial intraosseous success was defined as secure placement of the catheter within the bone cavity, as evidenced by marrow aspiration, normal fluid flow, and lack of surrounding tissue infiltration. Initial peripheral intravenous success was defined as secure placement within a peripheral vein; observance of back flow of venous blood in the intravenous catheter, followed by normal fluid flow; and lack of surrounding tissue infiltration. Overall success took into account a failure to maintain initial vascular access during the course of resuscitation, which included needle dislodgement or the inability to successfully administer medications or fluid at any time during the resuscitation.

Secondary outcome measures included the total number of attempts required for successful vascular access, time to successful vascular access, time to first advanced cardiac life support (ACLS) medication, and total volume of fluid infused during resuscitation. Time to successful vascular access was the interval between paramedic arrival on scene and documented successful vascular access placement. On-scene times were based on data received from the computer-aided dispatch system, and all patient care activity times were recorded by the on-scene fire department captain. Time to first ACLS medication was the interval between arrival on scene and first medication delivery. Total volume infused was documented by paramedics at death pronouncement on scene or on arrival to the emergency department (ED). During this study, pressure infusers were not used during out-of-hospital cardiac arrest.

Data Collection and Processing

After completion of each eligible out-of-hospital cardiac arrest response, paramedics called a study voicemail to report pertinent study data. This information included the study card number, the assigned method of vascular access, the successful method of vascular access, the total number of attempts required to obtain successful vascular access, and the total volume of fluid infused. The voicemail telephone number and above data points were listed on the back of each study card in a script format. This procedure was to be completed either in the...
ED after patient handoff or after termination of resuscitation in the field by cellular telephone. The study voicemail was checked daily by a research assistant, who recorded the information in a database.

Data were verified weekly by reviewing all electronic patient care reports. Any data discrepancies were discussed with the paramedic. The most common data discrepancy included intelligible remarks on the study voicemail, and this was an infrequent occurrence. Other demographic data and arrest characteristics were obtained from the electronic patient care reports by the research assistant while conducting data quality checks. Finally, after each out-of-hospital cardiac arrest, paramedics self-reported their total number of previous intraosseous attempts before study implementation and their comfort with vascular access on a performance survey. Comfort with the most recent vascular access attempt and overall comfort with gaining vascular access with the humeral intraosseous, tibial intraosseous, or peripheral intravenous route were reported on a 5-point Likert scale (very uncomfortable to very comfortable).

Primary Data Analysis

Results from an observational study that we conducted estimated a 33% and 52% decrease in first-attempt success at vascular access when the tibial intraosseous route was compared with the humeral intraosseous route.17 According to these data, we prospectively determined that a clinically important decrease in first-attempt vascular access success would be 35%. Therefore, power calculations estimated that we would need to enroll at least 50 subjects in each arm of the study to detect a significant difference in first-attempt success, with a type I error rate of 0.05 and a power of 0.80. This necessitated a total recruitment of no fewer than 150 subjects.

Primary analysis consisted of descriptive statistics, including counts, frequencies, means, SDs, 95% confidence intervals (CIs), medians, and interquartile ranges (IQRs) where appropriate. Two analyses were performed on the primary outcome of first-attempt vascular access success, intention-to-treat analysis and an as-treated analysis. In the intention-to-treat analysis, the frequency of first-attempt success was calculated for each arm of the study regardless of actual device used, whereas in the as-treated analysis first-attempt success was based on the device the patient received. Secondary outcomes were analyzed with intention to treat. The main outcome was reported as a proportion with corresponding 95% CIs, and a test of independent proportions was conducted with $\chi^2$. The Bonferroni multiple comparison procedure was performed to adjust for pairwise comparisons. The overall probability of making a type I error was set at 0.05, whereas the significance level for individual comparisons was set at .02. Secondary outcomes were assessed with ANOVA (normally distributed data), Kruskal-Wallis (non-normally distributed data), and $\chi^2$ analysis (categorical data). All data analysis was performed with Stata (version 10.1; StataCorp, College Station, TX).

RESULTS

Characteristics of Study Subjects

During the study period, there were 203 patients who experienced an out-of-hospital cardiac arrest, with 182 patients randomized to one of the 3 vascular access methods (Figure). The allocated method of vascular access was not used 13 times because of human error or situations beyond the control of the paramedic (9 in the humeral intraosseous group and 4 in the peripheral intravenous group). Characteristics of the study population overall and by method of vascular access are provided in Table 1.
Table 1. Population characteristics overall and by assigned access site.

<table>
<thead>
<tr>
<th>Population Characteristics</th>
<th>Total Population</th>
<th>Humeral IO, n=51 (28%)</th>
<th>PIV, n=67 (37%)</th>
<th>Tibial IO, n=64 (35%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>119 (65)</td>
<td>36 (71)</td>
<td>42 (63)</td>
<td>41 (64)</td>
</tr>
<tr>
<td>Female</td>
<td>63 (35)</td>
<td>15 (29)</td>
<td>25 (37)</td>
<td>23 (36)</td>
</tr>
<tr>
<td>Race, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>88 (48)</td>
<td>21 (41)</td>
<td>32 (48)</td>
<td>35 (55)</td>
</tr>
<tr>
<td>Other</td>
<td>94 (52)</td>
<td>30 (59)</td>
<td>35 (52)</td>
<td>29 (45)</td>
</tr>
<tr>
<td>Age, y, mean (SD)</td>
<td>64.5 (1.3)</td>
<td>61.2 (2.4)</td>
<td>64.7 (2.2)</td>
<td>66.9 (2.1)</td>
</tr>
<tr>
<td>Weight, kg, mean (SD)</td>
<td>97.3 (2.7)</td>
<td>103.9 (6.5)</td>
<td>97.7 (3.8)</td>
<td>91.5 (3.9)</td>
</tr>
</tbody>
</table>

Table 2. Frequency of initial vascular access success and success after displacements.

<table>
<thead>
<tr>
<th>Vascular Access Site</th>
<th>Intention-to-treat analysis (Total sample, n=182)</th>
<th>As-treated analysis (Humeral, n=42)</th>
<th>Overall Success, % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Success, % (95% CI)</td>
<td>Displacement, % (95% CI)</td>
<td></td>
</tr>
<tr>
<td>Humeral IO, n=51</td>
<td>71 (58–83)</td>
<td>20 (8–31)</td>
<td>51 (37–65)</td>
</tr>
<tr>
<td>PIV IO, n=67</td>
<td>49 (37–61)</td>
<td>6 (0–12)</td>
<td>43 (31–55)</td>
</tr>
<tr>
<td>Tibial IO, n=64</td>
<td>95 (90–100)</td>
<td>5 (0–10)</td>
<td>91 (83–98)</td>
</tr>
<tr>
<td>Humeral, n=42</td>
<td>64 (49–79)</td>
<td>24 (11–37)</td>
<td>40 (25–56)</td>
</tr>
<tr>
<td>PIV, n=63</td>
<td>46 (33–58)</td>
<td>5 (0–10)</td>
<td>41 (29–54)</td>
</tr>
<tr>
<td>Tibial, n=77</td>
<td>96 (92–100)</td>
<td>5 (0–10)</td>
<td>91 (84–97)</td>
</tr>
</tbody>
</table>

*P<.001.

Main Results

The frequencies of first-attempt success by method of vascular access for the intention-to-treat and as-treated analyses are displayed in Table 2. In the intention-to-treat analysis, first-attempt success at vascular access was significantly higher (P<.001) for individuals randomized to tibial intraosseous access (91%; 95% CI 83% to 98%) compared with that of either the humeral intraosseous access (51%; 95% CI 37% to 65%) or peripheral intravenous access (43%; 95% CI 31% to 55%). In the as-treated analysis, first-attempt success at vascular access decreased for patients in the humeral intraosseous and peripheral intravenous group but remained the same in the tibial intraosseous group. Patients who received a humeral intraosseous attempt were also significantly more likely to have the access device become dislodged during the course of the resuscitation compared with the tibial intraosseous and peripheral intravenous attempts (Table 2).

Paramedics indicated on their postcall performance survey that they had performed a median of 3 intraosseous attempts before study implementation and generally indicated that they were comfortable with the vascular access method assigned to them (Table 3). However, paramedics were significantly less likely to report being comfortable or very comfortable with the vascular access method assigned when that method was a humeral intraosseous placement.

An analysis of secondary outcomes is presented in Table 4. Time to initial success was significantly shorter for individuals assigned to the tibial intraosseous route (4.6 minutes; IQR 3.6 to 6.2 minutes) compared with those assigned to the humeral intraosseous route (7.0 minutes; IQR 3.9 to 10.0 minutes). There was no difference in time to success for either of the intraosseous routes compared with the peripheral intravenous route. There was also a significant association between the amount of fluid infused and the assigned method of vascular access, with the peripheral intravenous route having the highest median volume infused (800 mL; IQR 500 to 1,000 mL).

LIMITATIONS

This study tested only 1 intraosseous device and insertion process and was not designed to test safety or the end outcome for out-of-hospital cardiac arrest, survival to hospital discharge. Also, the various time measures reported in our data analysis were documented on a cardiac arrest time log by the fire captain throughout resuscitation efforts. Although time of paramedic arrival on scene and arrival at the patient were captured by Medic dispatch, the fire captain was responsible for recording time of successful intraosseous or intravenous placement, as well as time of first drug administration. These times were documented as accurately as possible, but small discrepancies could exist because a universal clock was not used.

Although patients were randomized to one of 3 study arms, they and their subsequent observations were naturally clustered under paramedic. However, we did not adjust for this potential correlation because the number of procedures performed by each paramedic across the 3 arms was roughly balanced. Though given the potential for clustering and subsequent correlation, our CI estimates may be more narrow than expected. A total of 113 paramedics performed at least 1 intervention in this study, with a median number of interventions performed per paramedic of 1. Paramedics performed an average of 0.45 (median 0) humeral intraosseous needle insertions, 0.59 (median 0) peripheral intravenous needle insertions, and 0.56 (median 0) tibial intraosseous needle insertions.

In addition, variables such as morbidity and mortality were not available for analysis. We were unable to correlate survival rates or return of spontaneous circulation to either vascular access method.
Table 3. Paramedic experience and comfort with vascular access methods overall and by assigned access site.

<table>
<thead>
<tr>
<th>Measures of Comfort</th>
<th>Total Population, n=182</th>
<th>Humeral IO, n=51 (28%)</th>
<th>PIV, n=67 (37%)</th>
<th>Tibial IO, n=64 (35%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of previous IO attempts,* median (IQR)</td>
<td>3 (2–4)</td>
<td>3 (2–5)</td>
<td>3 (1–4)</td>
<td>3 (2–4)</td>
</tr>
<tr>
<td>Comfort with most recent attempt, No. (%)</td>
<td>151 (83)</td>
<td>30 (59)</td>
<td>58 (87)</td>
<td>63 (98)</td>
</tr>
<tr>
<td>Overall comfort with devices, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humeral IO</td>
<td>88 (48)</td>
<td>29 (57)</td>
<td>31 (46)</td>
<td>28 (44)</td>
</tr>
<tr>
<td>PIV</td>
<td>175 (96)</td>
<td>50 (98)</td>
<td>65 (97)</td>
<td>60 (94)</td>
</tr>
<tr>
<td>Tibial IO</td>
<td>179 (98)</td>
<td>50 (98)</td>
<td>66 (98)</td>
<td>63 (98)</td>
</tr>
</tbody>
</table>

Table 4. Analysis of secondary outcomes by assigned access site.

<table>
<thead>
<tr>
<th>Secondary Outcomes, Median (IQR)</th>
<th>Humeral IO, n=51</th>
<th>PIV, n=67</th>
<th>Tibial IO, n=64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of attempts*</td>
<td>1 (1–2)</td>
<td>1 (1–2)</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>Time to initial success, min*</td>
<td>7.0 (3.9–10)</td>
<td>5.8 (4.1–8)</td>
<td>4.6 (3.6–6.2)</td>
</tr>
<tr>
<td>Time to drug administration after success, min</td>
<td>7.7 (5.2–12.2)</td>
<td>7.6 (5.1–9.7)</td>
<td>6.5 (4.8–6.6)</td>
</tr>
<tr>
<td>Amount of fluid infused, mL*</td>
<td>400 (200–650)</td>
<td>800 (500–1,000)</td>
<td>400 (250–550)</td>
</tr>
</tbody>
</table>

*Reported number of attempts before study implementation excluding any attempts during training.
†Results are reported as paramedics indicating that they were comfortable or very comfortable with the device in question.
*Pc<.001.

In the literature, intraosseous needle insertions have been linked to local wound infections, osteomyelitis, fat emboli, and compartment syndrome.\(^6,8,20\) During this study, there was no mechanism in place for EMS or hospital personnel to report complications in the use of the intraosseous device.

The average weight of patients in the humeral intraosseous group was greater than that of individuals in either of the other 2 arms of the study. This increased weight may have been associated with a difficulty in obtaining or maintaining vascular access. Because it was impossible for a study investigator to be present at each cardiac arrest during the study period, first-attempt success was a self-reported variable by each paramedic. A misclassification of this outcome variable may have occurred and could be attributed to the paramedic's negative perception of multiple attempts at vascular access. To limit this occurrence, outcomes were verified in a debriefing session conducted by Medic quality improvement personnel after each out-of-hospital cardiac arrest. Finally, there were 13 protocol violations that favored the tibial intraosseous route, which may have been an indicator of bias among paramedics for that route and therefore could have resulted in confounding of the study results.

DISCUSSION

To our knowledge, this was one of the first randomized controlled trials to assess the frequency of first-attempt success between the humeral intraosseous, tibial intraosseous, and peripheral intravenous routes. Results demonstrated that the tibial intraosseous route was the most effective method of gaining vascular access during out-of-hospital cardiac arrest. The frequency of first-attempt success at the tibial intraosseous route exceeded that of both the humeral intraosseous and peripheral intravenous routes by greater than 40%. Time to initial needle placement was decreased and needle dislodgements occurred less often when the tibial intraosseous route was used for initial vascular access.

Although the proximal humerus has been shown to be a feasible and effective site for out-of-hospital intraosseous needle placement in previous studies,\(^9,10,16\) its utility during out-of-hospital cardiac arrest proved to be suboptimal in this analysis. Initial first-attempt success was only 50%, with needle dislodgements occurring 20% of the time. This low rate of success could be attributable to the anatomic location of the proximal humerus. Compared with the proximal tibia, the proximal humerus has a smaller surface area and is not as easy to identify visually. Accessing this location requires correct positioning of the upper extremity to properly expose the humeral head, which, depending on the patient, is covered by a variable amount of subcutaneous tissue. As a result, paramedics must select the correct intraosseous needle length required to reach the bone cortex. If the selected needle is too short to fully penetrate all subcutaneous tissue, the intraosseous needle will fail to completely enter the bone matrix, leading to a failed attempt or dislodgement.

The proximal humerus can also prove tenuous during cardiac arrest because it is centered near the upper torso, where resuscitation efforts are occurring, including airway management, ongoing chest compressions, and rescuer interchange. The constant activity creates a tremendous amount of movement and further increases the risk of unintentional needle dislodgement, which was verified during the debriefing session after each out-of-hospital cardiac arrest, with paramedics frequently citing entanglement of the humeral intraosseous line, leading to dislodgement. On the contrary, the proximal tibia is isolated farther from these efforts, is easier to stabilize during resuscitation, and has a larger surface area with less subcutaneous tissue surrounding the bone.

Despite extensive training in the cadaver laboratory for both intraosseous insertion sites, paramedics may have been more
comfortable with the tibia compared with the humerus because of familiarity and previous experience at the tibia. This was illustrated on the performance survey, in which only 50% of paramedics answered being "very comfortable" or "comfortable" with the humeral intraosseous site compared with almost 100% at both the tibial intraosseous and peripheral intravenous sites.

The peripheral intravenous placement did not perform as well as expected during this study. The peripheral intravenous site is the most commonly used vascular access by all health care providers, yet it proved successful in less than 50% of cases in this study. A lack of experience or decreased comfort levels were not associated with peripheral intravenous failure. Research has demonstrated that intraosseous insertions are quicker than peripheral intravenous insertions, but few researchers have attempted to show one method of access as more effective than another.\(^9\) The cost related to intraosseous access, specifically the intraosseous needles, is much greater than the cost of peripheral intravenous catheters. To expand on this research, further studies should attempt to quantify the cost-effectiveness of vascular access in out-of-hospital cardiac arrest.

Twice the amount of fluid was infused through peripheral intravenous lines compared with that for both the tibial and humeral intraosseous needle insertions. There was no difference in the amount of fluid infused through the humeral intraosseous or tibial intraosseous routes. This relationship may have been confounded by an unequal distribution of transport times or patients pronounced dead on scene. These variables were not collected in this study; therefore, we were unable to control for this potential confounding. Literature reviewed and information provided by various intraosseous power device manufacturers did not list any adherences to fluid administration, other than the initial resistance experienced on initiating intraosseous saline solution infusions. This resistance is usually overcome after a 10- to 15-mL saline solution flush after initial needle placement in the bone matrix.\(^10\) Further studies are required to determine the validity of the association between fluid volume infused and vascular access method demonstrated in this study.

This randomized controlled trial demonstrated that a significant difference in the frequency of first-attempt success existed between tibial intraosseous needle insertions and humeral intraosseous or peripheral intravenous needle insertions among patients experiencing out-of-hospital cardiac arrest. To our knowledge, this was one of the first studies to randomize vascular access locations in out-of-hospital cardiac arrest to investigate effectiveness in the out-of-hospital setting. Results from this study may help stakeholders such as EMS medical directors choose the most appropriate site for first-attempt vascular access in out-of-hospital cardiac arrest.

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**Author contributions:** RR, JRS, SV, and JG conceived the study and designed the trial. RR, JRS, and SV supervised the conduct of the trial and data collection. JRS and SV managed the data, including quality control. JRS provided statistical advice on study design and analyzed the data. RR and JRS drafted the article, and all authors contributed substantially to its revision. RR takes responsibility for the paper as a whole.

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**REFERENCES**

IMAGES IN EMERGENCY MEDICINE
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DIAGNOSIS:

Acute generalized exanthematous pustulosis after cephalaxin use. A diagnosis of acute generalized exanthematous pustulosis as a result of cephalaxin was made in the emergency department. The patient was admitted for 2 days and received systemic and topical steroids; the rash significantly improved.

The incidence of acute generalized exanthematous pustulosis is estimated to be 1 to 5 cases per million per year, and 90% are drug induced. Antibiotics are the most frequent cause. Acute generalized exanthematous pustulosis presents acutely with dozens of nonfollicular sterile pustules on a diffuse erythema predominantly in intertriginous areas and on the face. Fever and increased blood neutrophil levels are common. Treatment consists of cessation of causative agent, supportive care, and use of steroids in severe cases.1

REFERENCE