Intraosseous Versus Central Venous Catheter Utilization and Performance During Inpatient Medical Emergencies

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Objectives: Intraosseous access is a rapid and effective route of fluid and drug administration. Its use has been proven in emergency medicine, pediatrics, and the military. We aimed to assess its performance and utilization against landmark-guided central venous catheter placement during inpatient medical emergencies.
Design: Prospective observational study.
Setting: Eight hundred fifty-six–bed urban teaching hospital.
Patients: Adult inpatients requiring central venous access during medical emergencies.
Interventions: Intraosseous device training was added to standard central venous catheter training beginning in February 2012. Intraosseous were used as primary access in cardiac arrests and secondary access if central venous catheter placement failed during noncardiac arrest emergencies. An online survey was conducted among intraosseous and central venous catheter operators to assess their experience and any barriers to use.
Measurements and Main Results: Seventy-nine adults had central access placement from February 2012 to July 2013. Sixty were during medical emergency team calls, and 19 were cardiac arrests. Thirty-one received intraosseous device, and 48 received a central venous catheter. First-pass success was significantly higher for intraosseous than for central venous catheter (90.3 vs 37.5%; 95% CI, 80–101 vs 24–51; $p < 0.001$). Mean placement times were significantly shorter for intraosseous than for central venous catheter (1.2 vs 10.7 min; $p < 0.001$). There were a total of 33 intraosseous versus 169 central venous catheter attempts with fewer attempts on average per patient during intraosseous placement (1.1 vs 2.8; $p < 0.001$). There were three intraosseous-related complications and 22 central venous catheter-related complications. Our survey showed high satisfaction with intraosseous training and operation. Among the barriers cited, timely intraosseous kit acquisition was most common.
Conclusions: It is feasible to incorporate intraosseous use during medical emergency team calls. Intraosseous had significantly higher first-pass success rates and faster placement compared with central venous catheters. Intraosseous operators reported high satisfaction and confidence in its use. Prospective randomized studies comparing intraosseous and central venous catheter are warranted. (*Crit Care Med* 2015; 43:1233–1238)

Key Words: central venous catheterization; intraosseous; intraosseous infusions; rapid response team; resuscitation; training

During medical emergencies obtaining prompt vascular access in a critically ill patient is an essential technical skill required of medical emergency team (MET) members (1). Landmark-guided central venous catheter (CVC) placement in femoral or subclavian veins has first-attempt failure rates of up to 40% and can take up to 8 minutes (2, 3). Patient factors, such as dehydration, obesity, and anasarca, make placement difficult resulting in complication rates of up to 17.3–36.6% (4–6). Ultrasound guidance has been shown to decrease these complications but may not be practical during emergencies (3, 6, 7).

Alternative means of vascular access such as the intraosseous route have been used for medication administration and resuscitation (8, 9). The intraosseous cavity is a noncollapsible space that contains a readily recruitable venous plexus that can be used for rapid drug delivery (3, 10, 11). It is generally underused in emergency departments and even less so on inpatient wards (11, 12). Early research in the prehospital setting and emergency department has shown that

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intraosseous devices outperform CVCs in terms of first-pass success rates, rapid placement, and complication rates after short training sessions (2, 13–15). The latest American Heart Association Advanced Cardiac Life Support guidelines support the use of intraosseous devices if intravenous access is not readily available (16).

We incorporated intraosseous use as a technical skill during MET training with the intent of decreasing the time to establishing central IV access. We hypothesized that intraosseous use among house staff trainees on METs would be superior to landmark-guided CVC placement in terms of success rates and time to placement.

MATERIALS AND METHODS

Setting

This is a single-center, prospective observational study conducted between February 2012 and July 2013 at an 856-bed urban teaching hospital. The use of intraosseous devices was approved for the use in our hospital in February 2012. Data were collected during adult inpatient medical emergencies as a part of a MET quality improvement initiative. All patient identifiers were omitted in our database. MET calls included patients in shock, respiratory distress, or cardiac arrest. Our institutional review board granted this study exemption from full review and patient consent.

Study Design and Protocols

METs consisted of post-graduate year (PGY) 1, 2, and 3 internal medicine house staff, nurses, a respiratory therapist, and a pulmonary/critical care fellow or attending. Rotating senior house staff on METs were provided standard monthly simulation instruction in CVC insertion as a part of their American Heart Association Advanced Cardiac Life Support & MET simulation training. The CVCs used were triple lumen, 7-French, 20 cm in length catheters (Arrow International, Limerick, PA). Percutaneous, landmark-guided CVC placement was performed by standard Seldinger technique, and the femoral vein was used as the primary site. Ultrasound guidance was not routinely performed during MET calls due to the emergent need for rapid vascular access and delays involved in obtaining an ultrasound machine.

A 60-minute intraosseous training and simulation program were incorporated into MET training beginning in February 2012. The EZ-IO system (Vidacare Corporation, Shavano Park, TX) consists of a stainless steel 15-gauge needle of various lengths (15, 25, and 45 mm) that magnetically attaches to a lithium-ion powered drill. The primary landmark for intraosseous placement in our institution was the medial aspect of the proximal tibia given its large target and ease of approach. The secondary target was the proximal humeral head if tibial placement failed or was contraindicated. Anatomical targets were avoided if the overlying skin was infected, there were prosthetic knees or limbs, unhealed fractures, or the site was previously accessed with an intraosseous needle.

During a MET call advanced vascular or intraosseous access was placed when the MET leader determined that peripheral IV access was inadequate. MET training instructors recommend intraosseous needles to be used as a rescue device if a CVC could not be placed in two attempts or within 5 minutes. In the instance of a cardiac arrest, MET leaders were instructed to use the intraosseous device as primary access. CVC or intraosseous placement was recommended to be deferred if the patient had in-dwelling central access, such as tunneled venous catheters, peripherally inserted central catheters, or at least two functional 20-gauge peripheral IVs. The MET leader made the final determination if central access was needed and which device should be utilized (CVC or intraosseous). Once sterile central access was established all emergently placed CVCs and intraosseous needles were removed (goal within 24 hours as per our standard infection control policy and procedures).

Data Collection

During CVC and intraosseous placement, an independent member of the research team observed and collected data on the house staff member who performed the CVC or intraosseous placement. Data were primarily collected during daytime and weekday hours. Data collection during nights and weekends was performed when feasible. CVC and intraosseous needle insertion times, number of attempts, anatomical location, number of kits used, patient body mass index (BMI), operator training level, and any complications were recorded. CVC insertion time was measured using a stopwatch from the opening of the CVC kit to the removal of the wire from the distal port and aspiration of venous blood from the CVC in a central vein. For intraosseous placement, time was measured from the opening of the kit to when marrow aspirates were confirmed from the attached tubing. An attempt was defined as a skin puncture with the CVC finder needle or intraosseous needle. A failed CVC was defined as the inability to place a CVC on each attempt, arterial cannulation, dislodged CVC, or defective equipment. Intraosseous failure was defined as inappropriate anatomic placement, defective equipment, dislodged intraosseous needle, or inability to aspirate marrow for confirmation. A more senior house staff member, critical care fellow, or critical care attending took over the procedure after failed attempts at the discretion of the MET leader. To assess for subsequent complications related to CVC or intraosseous attempts such as infection, vascular injury, or soft tissue injury, we inspected insertion sites 24 hours after initial placement.

Survey

At the 18th month, since introduction and training of intraosseous access, we conducted an online survey among all PGY-2, PGY-3, critical care fellows, and critical care attendings that have placed an intraosseous needle during MET calls (**Appendix 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/B222). The survey focused on the operator's experience with intraosseous and CVC training, satisfaction, ease of placement, and any barriers to their use. Responses were measured on a five-point scale (1 = not satisfied; 5 = very satisfied).

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Statistical Analysis

Our primary outcome was first-pass success rates of CVC and intraosseous placement. Secondary outcomes include time to successful placement of CVC or intraosseous, number of attempts, BMI, anatomical location, number of kits used, and complications related to CVC and intraosseous attempts. First-pass and overall success rates were expressed as percentages and analyzed using a two-sample test of proportions. Number of kits used, insertion times, attempts, and BMI were expressed as means and analyzed using a two-sample Wilcoxon rank-sum test. A value of p less than 0.05 was considered statistically significant. All statistical analyses were performed using Stata IC 13.1 MP (StataCorp, College Station, TX) and Excel (Microsoft, Redmond, WA).

RESULTS

MET Calls and Patient Characteristics

During our observation period, there were 787 MET calls (148 cardiac arrests and 639 noncardiac arrests). We observed emergent central access placement on 79 adult patients (19 cardiac arrests and 60 nonarrests). Types of medical emergencies encountered and rates of CVC and intraosseous insertion for each emergency are listed in **Table 1**. The most commonly encountered emergency was pulseless electrical activity (29 patients; 36.7%) followed by respiratory failure (hypoxic and hypercapneic; 14 patients, 17.7%). A total of 72 CVC operators and 33 intraosseous operators were observed during the study. There were 169 CVC and 33 intraosseous attempts reported. The training level of CVC and intraosseous operators can be found in Table 1.

Femoral CVCs were attempted in 48 patients as the primary device. Intraosseous were used as the primary device in 31 patients. The proximal tibia was more commonly attempted than the proximal humerus (25 vs 7, respectively). BMI data were available for 67 of 79 patients. There were no significant differences between patients who received CVC versus intraosseous (26.7 vs 30.0, respectively; $p = 0.25$).

Success Rates and Procedure Times

First-pass success rates were significantly higher during intraosseous attempts than during CVC, 90.3 versus 37.5%, respectively (95% CI, 80–100 vs 24–51, respectively; $p < 0.001$) (**Fig. 1**; **Table 2**). Overall success rates were also significantly higher during intraosseous attempts than during CVC, 96.8 versus 81.3%, respectively (95% CI, 91–103 vs 70–92; $p = 0.04$)

TABLE 1. Types of Medical Emergency Team Calls and Operator Training Level

Reason for MET Call	Central Venous Catheter	Intraosseous Access
Altered mental status, *n* (%)	9 (15)	2 (6.7)
Aspiration, *n* (%)	2 (3.3)	0
Gastrointestinal bleed, *n* (%)	1 (1.7)	1 (3.3)
Hypercapneic respiratory failure, *n* (%)	2 (3.3)	1 (3.3)
Hypoxic respiratory failure, *n* (%)	9 (15)	2 (6.7)
Pulseless electrical activity, *n* (%)	22 (36.7)[a]	16 (53.3)[a]
Status epilepticus, *n* (%)	1 (1.7)	0
Supraglottic edema, *n* (%)	1 (1.7)	0
Ventricular fibrillation, *n* (%)	0	1 (3.3)
Asystole, *n* (%)	3 (5)	4 (13.3)
Flash pulmonary edema, *n* (%)	0	1 (3.3)
Hypotension, *n* (%)	10 (16.7)[b]	2 (6.6)[b]
Total MET calls	60	30
Total attempts	166	33
Operator Training Level		
Critical care attending	8	1
Critical care fellow	6	7
PGY3	28	13
PGY2	30	12

MET = medical emergency team, PGY = post-graduate year.
[a]Nine central venous catheter (CVC) were converted to intraosseous).
[b]Two CVCs were converted to intraosseous.

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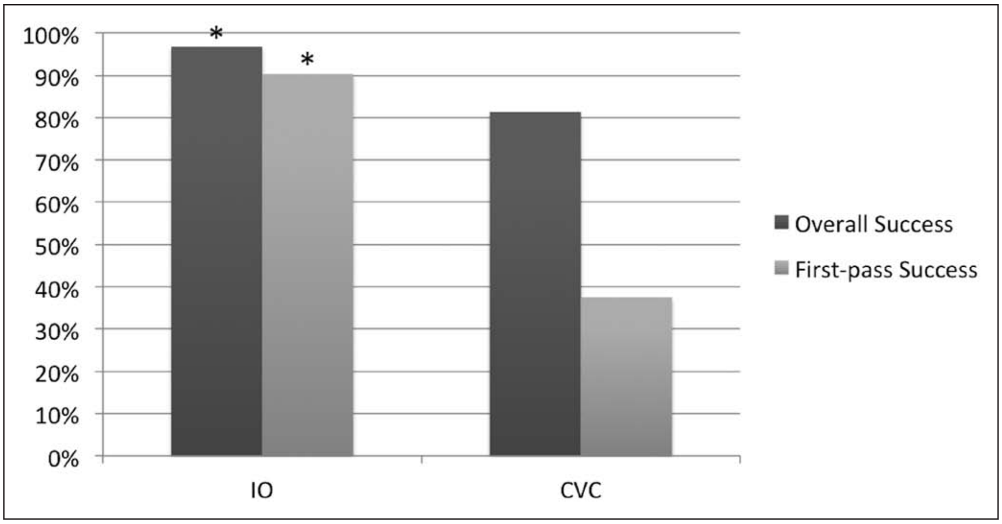

Figure 1. Overall and first-pass success rates of intraosseous access (IO) and central venous catheter (CVC). *$p < 0.001$.

(Fig. 1; Table 2). Procedure times were available for 48 patients who received CVCs and 29 patients who received intraosseous (Table 2). CVC placement took significantly longer when compared with intraosseous (10.7 vs 1.2 min; $p < 0.001$). Mean CVC attempts per patient were significantly higher (2.8 vs 1.1; $p < 0.001$) with more CVC kits used, on average, per patient than intraosseous (1.3 vs 1.1, respectively; $p = 0.03$).

Complications

Sixteen of 22 CVC complications were due to arterial punctures, four of which led to bleeding from the puncture site. Other complications related to CVC placement were bladder puncture and a kinked guide wire (**Table 3**). There were three complications related to intraosseous placement. One misplaced intraosseous resulted in extravasation of vasopressors into the subdermal space causing tissue necrosis. This patient required surgical debridement of the wound and survived her injury. One patient experienced significant pain during fluid infusion into an intraosseous placed in the proximal tibia. Another patient's intraosseous needle was poorly secured to the proximal humeral head and was dislodged during transport.

Survey Results

Surveys were distributed to 48 MET members who were trained in intraosseous and CVC use. The response rate was 66.7% ($n = 32$). Seventy-five percentage of respondents consisted of PGY2 and PGY3 house staff ($n = 11$ and 13, respectively). MET members' subjective rating of their confidence with intraosseous placement resulted in a median response of 4 (interquartile range, 3.5–5.0). 81.3% recalled successful first-pass intraosseous attempts. Despite a median confidence score of 4.5 (interquartile range, 4.0–5.0) for CVC placement, nearly 60% of respondents recalled multiple failed attempts. During the observation period, a number of barriers to intraosseous kit use were encountered. The most notable were related to delays in intraosseous kit acquisition (28.1%), followed by poorly stocked kits (6.3%).

DISCUSSION

In our study, intraosseous placement had first-pass success rates superior to landmark-guided CVC placement during adult inpatient medical emergencies. Our first-pass intraosseous success rate of 90.3% is similar to prior observational studies among paramedics and emergency physicians (2, 13, 14). Furthermore, our successful intraosseous placements were rapid with an average time of 1.2 minutes when compared with CVC times of 10.7 minutes. This difference in placement time is consistent with prior studies among emergency department providers comparing intraosseous placement against peripheral IVs and CVCs (2, 15, 17).

It is known that prehospital and emergency providers at every level can learn to place intraosseous needles (3, 11, 13, 14, 18). We demonstrated that it is feasible to incorporate this new technical skill into our MET program with similar results. Despite the familiarity of landmark-guided CVC placement, it is a technical skill that is difficult to master among trainees. It has been suggested that at least 50 insertions are needed to achieve minimal competence (19, 20). Even in experienced hands, successful first-pass

TABLE 2. Success Rates and Placement Times for Central Access

	Intraosseous Access Patients ($n = 31$)	Central Venous Catheter Patients ($n = 48$)	p
First-pass success rate, %	90.3 (28/31)	37.5 (18/48)	< 0.001
Overall success rate, %	96.8 (30/31)	81.3 (39/48)	0.043
	Intraosseous Access Patients $n = 29$	**Central Venous Catheter Patients $n = 48$**	**p**
Placement time (min), mean	1.2	10.7	< 0.001

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TABLE 3. Complications Associated With Attempts to Establish Central Access

Complications	Central Venous Catheter, *n* (%)	Intraosseous Access, *n* (%)
Arterial puncture	16 (33.3)	NA
Bladder puncture	1 (2.0)	NA
Guidewire kinked	1 (2.0)	NA
Bleeding from site	4 (8.3)	NA
Extravasation and skin necrosis	0	1 (3.0)
Pain	0	1 (3.0)
Dislodged access	0	1 (3.0)
Total complications	22/48 (45.8)	3/33 (9.1)

NA = not applicable.

placement is shown to vary between 27% and 60% with complications rates up to 25% (2, 21, 22). Our MET providers failed in nearly 65% of first-pass attempts versus 10% of intraosseous. This higher failure rate may be explained by the fact that MET house staff in our study rotate monthly so each provider has very few opportunities to place emergent CVCs. The achievement of minimal competence with high-risk, low-frequency events can be difficult during medical training (23, 24).

Complications from intraosseous insertion were far fewer when compared with CVC placement (three of 31 vs 24 of 48 patients, respectively). Most CVC complications we encountered were due to arterial punctures and bleeding, but there were no severe adverse sequelae. Although the true complication rate of intraosseous use is unknown, literature suggests that it is less than 1% (11, 14, 25, 26). Extravasation of medications causing skin necrosis and needle dislodgement are the most commonly cited which we also encountered. We experienced no infectious complications or incidence of fat emboli among our cohort. The complications of extravasation and dislodgement happened very early in the implementation phase that we believe was due to unfamiliarity with the new device and proper needle length selection.

Ultrasound guidance for CVC insertion has shown to significantly improve first-pass success rates and decrease mechanical complications (6, 20–22). However, routine use of ultrasound in emergencies may be impractical because ultrasound machines may not be readily available, patients' rooms can be crowded during emergencies and setting up the machine may waste time (19–21). Although some providers may not be ready to abandon CVC placement altogether perhaps proactive supervision required to teach ultrasound fundamentals, hand-eye coordination and familiarity with vascular anatomy should take place under controlled settings (19, 22, 27). The alternative use of intraosseous needles on the hospital wards should, instead, be viewed as a "bridge" to resuscitation with the goal of placing a sterile, ultrasound-guided, CVC in an ICU (25).

Our study is the first to examine MET utilization of intraosseous in the emergent inpatient setting. There are several limitations in our study, however. Our study population was a small convenience sample and limited to a single institution. The sample size is reflective of the frequency of MET calls at our hospital. Furthermore, we may have missed some intraosseous and CVC insertions because data collection during the weekends and overnight was inconsistent. Additionally, because the EZ-intraosseous system is a new device to our hospital and more expensive than a standard CVC kit, we restricted its use to first-line access in cardiac arrests and as second-line after failed CVCs in all other instances. As a result of the protocol design, there were disproportionately more CVC attempts than intraosseous. Furthermore, the number of complications we experienced respective to each device would be better assessed with a larger sample size. However, given the inherent differences in mechanical operation and anatomic targets of each device, the types of complications would be difficult to compare.

Finally, as our focus was on the feasibility of technical skills training and subsequent performance, we did not factor direct costs into our outcomes. Dolister et al (25) recently conducted a multicenter prospective observational study comparing intraosseous placement to published CVC data. Despite the relatively higher cost of a single intraosseous needle compared with a CVC kit, Dolister states that there is a potential for cost-savings if professional time, materials, and central line associated blood stream infections are factored in. The use of intraosseous needles as a bridge during resuscitation requires a single operator, significantly less time and materials, and is associated with far fewer infectious complications (11, 25).

CONCLUSIONS

During medical emergencies, intraosseous needles are a much faster means to obtain central access with first-attempt success rates superior to CVCs. Their use can potentially lead to earlier administration of time-sensitive therapies. Operators, including junior trainees, show both high satisfaction and confidence with its use. Intraosseous access should be considered during adult inpatient emergencies. Prospective randomized studies comparing emergent intraosseous versus CVC placement are warranted.

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