JEMS CLINICAL REVIEW FEATURE

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Hurts So Good

EASING IO PAIN AND PRESSURE

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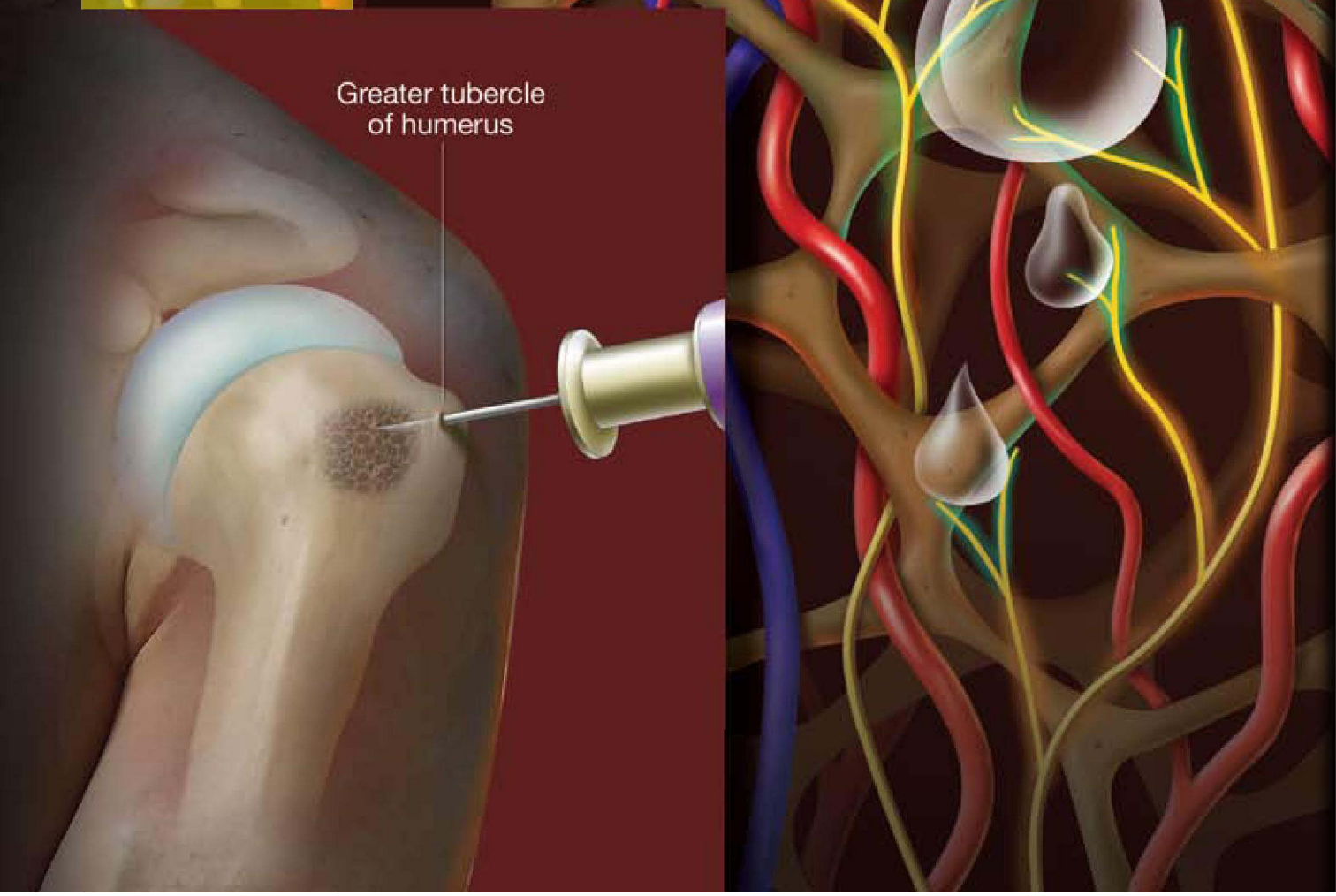

Intraosseous (IO) vascular access, which involves inserting a needle into the bone-marrow cavity for administering fluids and medications, was first proposed in the 1920s.[1] Studies from the '40s showed the effectiveness of the IO route in children, which led to its acceptance as a clinically useful technique.[2,3]

During World War II, IO was widely used for adults. However, IO use declined in the late '40s due to a lack of advanced-level civilian prehospital emergency care following the war and increased popularity of plastic catheters for IV access.[4] Today, improved IO devices enable clinicians to consistently and safely access the vascular system quickly. Drug delivery through the IO route to the systemic circulation is often as quick as through central venous catheters and faster than through peripheral lines.[5,6]

In most cases, two conditions must be met for optimal IO flow rates. First, the IO space must be flushed under high pressure with a syringe. Then, to achieve and maintain adequate infusion pressure, a pressure-infuser bag or a standard automated IV infusion pump that generates 300 mmHg is required. Gravity alone will rarely generate an adequate flow rate, and sufficient pressure can't be attained by manually squeezing the IV bag because of the inherent IO pressure of the **medullary space**.

Although the pain is known to immediately **desist** with cessation of the infusion pressure, higher pressures yield faster infusion flow rates and are considered essential in the delivery of emergency medications and fluids.

But pain associated with IO insertion and infusion in conscious patients is a well-documented reality that must be dealt with in the field. One study found the mean pain level in patients with a Glasgow Coma Scale (GCS) score of > 12 increased from 3.5 on insertion, to 5.5 on infusion.[7] Their assessment—and the observation that the patient's pain level can be substantially reduced by injecting preservative-free lidocaine through the IO port prior to the infusion—coincided with the **anecdotal** experiences often described by users of any IO device.

Anecdotal experience and published literature support the effectiveness of the lidocaine injection prior to IO fluid infusion to control the pain.[8–10] The dosage typically administered to adults—40 mg, occasionally followed by another 20 mg—is well below the maximum dosage of 300 mg over a one-hour period that's recommended by lidocaine manufacturers.[11]

Traditionally, the proximal **tibia** has been the site most commonly used for IO insertion. But there's new interest in the proximal **humerus** as a preferred site because fluids tend to flow easier through the humerus, requiring less pressure to deliver the initial flush.[12,13] Less pressure results in less pain.

Until recently, no studies have compared the levels of pain experienced during IO infusion at the tibial and humeral sites, nor have they evaluated the effectiveness of lidocaine to mitigate the pain. To validate recommendations on humerus use and IO pain management, we designed two studies to compare lidocaine's effect on pain during fluid infusion through the tibial and proximal humerus sites and to determine the relationship between infusion pressure and flow rates delivered through the two sites.

METHODS

Design and setting: Two non-randomized studies were approved by the IntegReview Institutional Review Board (IRB) and conducted in a dedicated multi-specialty research facility. The first study used the proximal left and right tibial sites. The second study used the right proximal humeral site.

Participant selections and interventions: Healthy, pain-free, adult volunteers were recruited for and consented to the studies. Following a review of medical history, physical examination and vital signs, baseline pain scores using the **visual analog scale** (VAS) ranging from 0 to 10 were collected, and participants were connected to a cardiac monitor for observation during the study procedures. A 15-gauge IO catheter was inserted into the proximal tibia or proximal humerus.

For the tibial study, the left tibia was accessed first, and 40 mg of 2% preservative-free lidocaine was administered through the IO catheter over about two minutes, followed by a 10 mL normal saline bolus over five seconds. An additional 20 mg of lidocaine was then administered over 30 seconds. Eighty mg of lidocaine was administered through the right tibia IO catheter over about two minutes, followed by a 10 mL normal saline bolus over five seconds, and then, an additional 20 mg of lidocaine was administered over 30 seconds.

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Studies first showed the effectiveness of the intraosseous route in pediatric patients.

For the study on the proximal humerus, 40 mg of 2% preservative-free lidocaine was administered through the IO catheter in the right humerus over a period of about two minutes, followed by a 10 mL normal saline bolus over five seconds and an additional 20 mg of lidocaine over 30 seconds. A normal saline infusion was started, and infusion pressure was set at 100 mmHg using a 1,000 mL pressure bag. It was monitored by use of an electronic digital manometer connected in-line with the IV tubing. After 60 seconds, the infusion pressure was increased to 150 mmHg, and the same sequence was fol-

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LEARNING Objectives

>> Describe the historical origins of IO vascular access.
>> List two advantages of IO infusions.
>> Identify two acceptable landmarks for IO needle infusions.
>> Identify the IO site that provides the least amount of pain and has the best fluid flow rate.
>> Report the purpose of lidocaine use in IO infusions.

lowed for pressure increases to 200 mmHg, 250 mmHg and 300 mmHg.

Using the VAS, pain assessments immediately followed each injection and infusion pressure increase. If the pain became intolerable to the volunteer at any point during infusion, the pressure was released to relieve the pain instantly.

Measurement methods: At each pressure level, the IO infusion flow rate was calculated by visually counting the drops of fluid as they passed through the IV tubing drip chamber and converting the drops per minute to milliliters per hour.

As the infusion rate increased to the point that the drops couldn't be counted, the flow rate was calculated by weighing the infusion bag on a digital scale, timing the infusion for 60 seconds, weighing the bag again and subtracting the second weight from the first.

To determine the duration of the lidocaine's effectiveness for pain management, the infusion pressure was reduced to 200 mmHg, and the volunteer was observed for up to 90 minutes starting at the time of the second lidocaine injection.

In the tibial study, this observation period occurred following the interventions in the right leg only, which included a total of 100 mg of lidocaine. For the humeral study, this observation occurred following interventions in the right arm, which totaled 60 mg of lidocaine. During this observation period, pain was assessed every 10 minutes, and subjects experiencing a pain score of 5 or higher were given another 20 mg lidocaine injection.

At the end of each 90-minute study period, the IO catheter was removed, and volunteers were asked to score the pain of catheter removal.

To ensure safety following the IO catheter removal, volunteers were required to wait in the study facility at least 30 minutes before departure. Follow-up telephone calls for pain assessment and complications were made at 24 hours and seven days.

Data collection and processing: Data were initially captured on paper data collection records and subsequently entered into an electronic database. Descriptive statistics were calculated using predictive analytics software (PASW) statistics.

RESULTS

Ten volunteers were selected for each study. Five participants from the first (tibial) study also participated in the second (humeral) study. One participant who started the humeral study withdrew after the IO insertion, due to intolerable pain and anxiety, and was replaced by a standby volunteer candidate. Of the 16 total participants, nine were female and seven were male. The mean age was 34.3 ± 7.7 years (range=23–48).

All IO insertions in both studies were successful on the first attempt. The mean IO insertion VAS pain score was 4.4 ± 2.6 (range=0–6) for left tibial insertions, 3.6 ± 2.3 (range=1–10) for right tibial insertions and 3.0 ± 1.5 (range=1–7) for humeral insertions.

For the duration of each study, the highest mean VAS pain score occurred during the normal saline flush: The mean score was 6.8 ± 2.9 (range=1–10) for the left tibia, 7.9 ± 2.8 (range=2.5–10) for the right tibia and 4.6 ± 2.9 (range=1–10) for the humerus.

During the 90-minute observation period following the initial interventions, eight of 10 volunteers in the tibial study (who had previously received 100 mg of lidocaine) required an additional 20 mg dose of lidocaine to keep the pain level less than 5.

The mean amount of elapsed time before the additional dosing was required was 39 ± 20 minutes. No volunteers in the humeral study (who had previously received 60 mg of lidocaine) required additional lidocaine dosing to keep the pain level to less than 5.

The highest mean infusion flow rate was achieved at 300 mmHg infusion pressure for both studies. For the left tibia, the mean flow rate at that pressure was 828 ± 231 mL/hour (range=360–1,152 mL/hour). For the right tibia, the mean flow rate at 300 mmHg was 1,048 ± 831 mL/hour (range=336–3,300 mL/hour). For the humeral study, the mean flow rate at that pressure was 5,093 ± 2,632 mL/hour (range= 828–9,000 mL/hour)

GLOSSARY TERMS

Anecdotal: Based on random observations rather than scientific investigation.
Desist: To stop or cease an activity.
Humerus: The bone that makes up the proximal portion of the upper limb.
Intraosseous: Situated within a bone or entering a bone.
Medullary space: The inner cavity located inside the bone.
Tibia: The bone that makes up the distal portion of the lower limb.
Visual analog scale: A subjective pain scale that's used to rate the presence of pain in a patient who's undergoing a potentially uncomfortable procedure. Pain is rated on a 1 to 10 scale. A score of 0 means that there's no pain. A score of 10 is considered agonizing pain.

LIMITATIONS

We believe that actual patients, rather than volunteers, might have provided more relevant feedback. However, assessments of pain levels in actual emergency patients generally present the following challenges:

- >> Distracting injuries make assessment of the primary pain unreliable. For example, neck fractures may be missed if there's also a leg fracture.
- >> Such painful interventions as IV access, spine boards and patient movement to the back of an ambulance tend to modify pain levels in the primary site.
- >> The physical and psychological stressors of the emergency situation result in the release of catacholamines, which mitigate pain in some cases and exacerbate it in others.
- >> Several concurrent activities with different priorities are usually going on at an emergency scene. Many reports of pain levels and response to treatment are anecdotal. For example, the patient was screaming, so the pain was recorded as level 10, and the patients stopped screaming after an intervention; therefore, the pain must be much less or gone. It may not be possible to consult with the patient.

In emergency situations, it would be difficult to brief patients on a pain study and expect them to concentrate on accurate reporting of such pain for study purposes. Patients can be affected by scene distractions, anxiety about their condition or the perception that exaggerating or denying pain levels may alter their course of treatment.

We considered these limitations and decided to use healthy volunteers in a controlled setting, who were briefed on the procedures and understood the metrics used to assess pain levels during the study.

Patient understanding of dental procedures and pain relief are well documented.[14–16] In the case of pain associated with the insertion of the IO device and pain levels during various infusion pressures, it would be impossible to subject an actual emergency patient to an hour of systematic induction of pain to various infusion pressures and perform studies with scientifically reproducible results.

Yet, as use of IO infusion becomes more widespread and is used in conscious patients for medically necessary procedures, it will become increasingly important to understand the relation of infusion pressure to pain and the amount of lidocaine necessary to reliably alleviate the pain.

Another limitation of the flow-rate portion of our study is that participants were relatively young adults who were healthy and normotensive. It's unknown how these pain levels and flow rates might have differed in pediatric or elderly patients. We're unable to predict

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how the flow rates might differ in hypertensive patients or those in shock. However, we believe the results showing higher infusion flow rates in the proximal humerus would be replicated in actual patients.

DISCUSSION

The authors of one retrospective study of 1,128 patients receiving IO vascular access reported that patients with a GCS score > 12 experienced VAS pain levels of 3.5 on IO insertion and 5.5 on infusion.[7]

The IO insertion site for most of these patients was the proximal tibia. The mean insertion pain in that study was similar to that experienced by volunteers in our tibial study (mean VAS score of 4.0) and somewhat greater than that experienced in our humeral study (mean VAS score of 3.0). Perhaps more importantly, the infusion pain of 5.5 in the retrospective study was greater than that generally experienced in ours, which peaked at 2.9 during infusion in the tibial and 1.4 in the humeral study.[7]

This can be attributed to several factors. IO infusion through the tibia is typically more painful, and the pain is more difficult to manage than when infusing through the humerus for conscious patients.

In our study, pain was greatest with the normal saline flush prior to infusion, but the need to deliver the quick flush over a period of five seconds or less can't be overstated because bone marrow blocks the flow. Often, pressures as great as 300 mmHg aren't enough to overcome this resistance.[1]

In addition, an inherent pulse pressure must be overcome before any positive flow can be achieved. But the higher pressure delivered through a 10 cc handheld syringe effectively flushes the marrow and fibrin into the circulation, leaving behind an open channel for IV fluid flow.

Recently, a non-randomized prospective observational study compared flow rates.[17] Flow rates in our study were typically substantially lower than the mean flow rates of 9,900 mL per hour and 9,180 mL per hour for the tibia and humerus, respectively, but still adequate for most EMS applications.

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Until recently, no studies have compared the levels of pain experienced during IO infusion at the tibial and humeral sites.

The proximal tibia is most often used for IO vascular access, and the clinical literature supports it. But that trend may be changing.[4,7–9,16] In a 2009 study that reported using the proximal humerus as a primary site, the first of its kind, the authors made a strong case for using both the tibia and the humerus based on the ease and speed of obtaining access and the outstanding infusion flow rates.[17]

A more recent study, designed to assess humeral IO catheter placement as a preferred method for venous access compared to using peripheral IV (PIV) and central venous catheters (CVC) during emergency resuscitation, concluded that humeral IO place-

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ment is significantly faster than PIV and CVC placement.[18] Our studies generally validate and complement these two studies, including by obtaining vascular access quickly and on the first insertion attempt with both sites.

One purpose of the tibial study was to compare the levels of pain with an initial dose of 80 mg of lidocaine to the pain experienced with an initial dose of 40 mg. We concluded there was no clinical difference between the two initial doses and that an initial dose of 40 mg, followed by an additional 20 mg dose after the normal saline flush, provides reasonable pain management. For the humeral study, we opted to examine the 40 mg lidocaine/normal saline flush/20 mg lidocaine schema only. It's important to note that we firmly believe that in most cases, the second dose—20 mg in our study—of lidocaine, following the saline flush, is key to keeping the patient comfortable during IO infusion.

The reason for this is unclear. But we postulate that, following the initial lidocaine dosing, the saline flush opens new pathways in the IO space that are susceptible to infusion pain. We suspect the second dose of lidocaine reaches those areas and provides additional relief.

Overall, pain was successfully managed for the tibia and the humerus using 2% preservative-free lidocaine, and adequate infusion flow rates were obtained. But at every intervention, the pain was substantially less using the humeral site, and the difference was clinically significant. In our humeral study, one volunteer experienced intense pain during the IO placement and declined further participation in the study.

Recognizing the subjectivity of measuring pain in general and the variability among study participants, we consider the level of pain experienced by this participant as an outlier and not representative of the pain experienced by other participants in either of the two studies.

Operators should review the manufacturers' recommendations on the use and contraindications for use when administering lidocaine. Ultimately, EMS medical directors or attending physicians must determine the appropriate dosage of lidocaine.

The proximal humerus site should be strongly considered for optimal infusion flow rates and easier pain control. In the proximal humerus, a longer (45 mm) IO needleset may be the catheter length of choice.

In the tibial study, 100 mg of lidocaine was

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administered during the initial intervention while only 60 mg of lidocaine was administered in the humeral study. During the 90-minute observation period that followed initial interventions in the tibial study, eight volunteers required an additional 20 mg dose of lidocaine to keep the pain level less than 5. For these volunteers, the extra dosing was required after an average of 39 minutes, following their second dose of lidocaine. No volunteers in the humeral study required additional lidocaine during the 90-minute observation period. This is further evidence of the ability of the clinician to better manage pain with less medication when using the humeral site.

Moreover, there was a tremendous difference in infusion flow rates, again, in favor of the humeral site. For these reasons, we believe the proximal humerus should be strongly considered as the primary site when IO vascular access is needed.

Finally, a needle as short as 25 mm is usually adequate for tibial access due to minimal tissue between the skin and the bone. Due to the thicker tissue overlaying the proximal humerus, we used a 45 mm needleset, and there was little to no excess needle length remaining once the catheter was in place.

None of the participants were obese, and only one was heavily muscled. Based on this experience, we recommend that a longer needle be used for humeral insertion, rather than the shorter needleset typically used for tibial insertion. To avoid catheter dislodgement from the humerus, conscious patients should be instructed to avoid excess movement of the arm and to keep the arm in the same position as when the IO was inserted. In unconscious patients, the arm should be well secured in an adducted position.

CONCLUSION

For adequate IO infusion rates, a rapid 10 mL syringe flush is required, followed by a pressure infusion. The higher the infusion pressure, the higher the flow rate in all sites. The humerus site provides a higher flow rate than the tibia.

For tolerable pain control during fluid administration, 40 mg of preservative-free lidocaine may be needed, followed by a rapid normal saline syringe flush of at least 10 mL and another 20 mg of lidocaine. Additional dosing and flushing may be required. JEMS

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Disclosure: The authors are affiliated with Vidacare Corporation, a manufacturer of intraosseous insertion needles and devices.

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REVIEW QUESTIONS

Test your comprehension with this post-article quiz. Answers are provided at the end. Photocopying is permitted for non-profit training purposes only. For readers in need of continuing education credits, please visit JEMSprepare.com to choose from courses that are CECBEMS approved and meet NREMT refresher requirements.

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1. Which of the following statements regarding the origins of intraosseous (IO) infusion is accurate?
   a. IO infusion was proposed by Nancy Caroline in the 1960s.
   b. During the 1950s, IO infusion was widely accepted and used in civilian populations.
   c. IO infusion was made popular because plastic catheters became unsafe during World War II.
   d. IO was proposed in the 1920s and is faster than peripheral lines.

2. Which two conditions must be met for optimal IO flow rates?
   a. IO space flushed with a high-pressure syringe and the use of pressure bags, which can generate pressures of > 300 mmHg
   b. Gravity and manually squeezing of an IV solution bag
   c. Gravity and the use of pressure bags, which can generate pressures of < 300 mmHg
   d. High-pressure syringe for flushing and a high-pressure syringe for aspiration for needle placement assessments

3. Of the following sites, which is considered a desirable IO insertion site?
   a. The distal portion of the humerus
   b. The proximal portion of the humerus
   c. The distal portion if the tibia
   d. The mid-shaft portion of the tibia

4. Which IO site provided the best IV solution flow rate and the least amount of pain?
   a. The sternum
   b. The proximal tibia
   c. The proximal humerus
   d. The distal femur

5. What's the primary role of lidocaine use in IO infusions?
   a. The reduction of pain associated with IV fluid flow
   b. The treatment of possible premature ventricular contractions
   c. The stabilization of membranes and depression of action potentials
   d. The reduction of intracranial pressure and prevention of bradycardia

1. D, 2. A, 3. B, 4. C, 5. A