Intraosseous Access in Resuscitation

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Overview

• Introduction
• History
• Current usage
• Pharmacology/kinetics
• Potential complications
• Conclusions
Introduction

• What is intraosseous access?
  – Needle injected/implanted through hard bony cortex into vascular marrow bed
  – Allows direct access to systemic vascular system
Drawing courtesy of Vidacare Corp, San Antonio, Texas.
Types of IO

- Manual IO
  - Multiple types/manufacturers

- EZ-IO
  - Drill and bit system
  - Used at HFH

- FAST1
  - 6 prongs with central catheter
  - For use in sternum only, preferred in military/tactical situation

- BIG
  - Bone injection gun
  - Used only on proximal tibia
History

• First proposed in 1922 by Drinker, et al after examination of circulation of sternum
• Not used clinically until 1934
• Became widely used in Europe in 1940s during WWII
• Fell out of favor in United States in 1950s as plastic catheters for IVs became widely available
Re-Introduction

• Renewed interest in 1980s with article by Cleveland Clinic pediatrician working in India during cholera outbreak
  – “My Kingdom for an Intravenous Line”
• Became widely adopted in US for pediatric resuscitations in 1980s
  – Integrated as part of PALS
• Slower adoption into adult resuscitation
  – 2005 International Resuscitation Committee made part of guidelines when IV access cannot be obtained
Indications and Contraindications

**YES!**

- limited vascular access due to aggressive treatment modalities, eg, fistulas, grafts, shunts, mastectomies, or multiple central line placements.
- by Rapid Response Teams are called in order to prevent an emergent situation when obtaining peripheral or central IV access is difficult.
- after a peripheral or central IV device becomes unexpectedly non-functional, eg, infiltration or occlusion, and difficult to reestablish.
- who have limited peripheral access due to morbid obesity.
- who are in the early stages of sepsis.
- who are undergoing anesthesia and experience prolonged, difficult, or failed IV access.

**NO!**

- Fractures in the same extremity as the targeted bone
- Previous surgery involving hardware in the bone targeted for IO access – joint replacement, IM nailing
- Infection at the insertion site or within the targeted bone
- Local vascular compromise
- Previous failed IO insertion within 24 hours in the targeted bone
- Inability to locate landmarks

Relative Contraindications:
Osteoporosis, osteogenesis imperfecta, burns
“Despite the potential advantages of using IO, doctors remain reluctant to use the technique in resuscitation. This could delay the administration of potentially life saving drugs and fluids to patients with critical illness…little is known about why clinicians sometimes do not perform IO in cases where the indications are to do so.”

- **Swedish survey of emergency care providers**
  - online survey format, 759 responses - 23.5% (n=178) having a time where an indicated IO was not done
Survey Results

• Reasons cited for not placing IO
  – Equip not avail (48%), lack of training (32%), intravenous access *preferred* (23%), other staff against procedure (13%), concern about damage/pain in patient (11%)

• Limitation
  – Survey model – unable to verify accuracy of responses
Why would IV be preferred over IO?

- Pharmacokinetics
- Fear of potential complications
- Unfamiliarity with procedure
- ???
Why use IO?

AHA/ILCOR recommend IO be used in situations where IV access is delayed or impossible - BOTH in pediatric and adult resuscitation patients.

Remember: time is myocardium, brain...
• 30 swine, anesthetized/vented, PA catheter placed via EJ, CVC placed in IJ, tibial IO placed
• VF was induced with pacing electrode after baseline hemodynamic measurements taken
  – 10 min period of untreated VF, followed by compressions, defibrillation
  – Animals assigned to rapid IO or delayed IV epinephrine, with saline placebo as controls
  – IO access within 1 min or IV access at 8 min – meds given at 135 sec intervals after appropriate start time based on randomization
Results

- Fewer shocks required in IO group
- Faster ROSC
- No difference in rate of ROSC, but improved neurologic outcomes
Early IO vs Delayed IV

- **Conclusions**: early administration of epinephrine via IO is preferred to delayed IV access – leads to improved 24 hour survival rate.

- **Limitations**:
  - Swine model
  - Animals were young, healthy – presumably no CAD or other confounding factors
  - Used a higher dose of epinephrine than is used in human protocols
• Prospective, observational study in ED
  – 40 adult patients – consecutively enrolled “severely injured or critically ill” patients presenting without at least 1 “efficient” 18 ga PIV
  – Attempted IV access x 3 or to max of 2 min
• Anesthesiologist with >25 landmark based CVC placement placed central access while surgeon placed IO
  – Proximal humerus was preferred IO access site, RIJ or subclavian for CVC
• Success rate and time to successful placement
Results

- 6 unsuccessful IO – all failed to penetrate cortex (4 due to positioning, 2 due to excessive soft tissue)
- 16 CVC failed – inability to advance/insert guidewire cited as reason in all
- Success rate 85% with mean time of 2 min for IO, 60% with mean time of 8 min for CVC
Comparison of time to IO vs CVC

• **Conclusions:**
  – IO is viable as “bridging” procedure to obtain IV or CVC in patients in the ED

• **Limitations**
  – Small sample size
  – Not randomized or blinded
  – No use of US (authors cited increased time of procedure as reason)
  – Authors noted definition of expert was “arbitrary and may not truly reflect familiarity with procedure”
• Prospective, non blinded, triple arm RCT
• Enrolled all patients with out of hospital cardiac arrest in 5 month period in 2010
  — Traumatic arrests, pediatrics, patients with access present, DNR order, or contraindication to IO excluded
• Patients randomized to proximal tibial IO, proximal humeral IO, or peripheral IV – 182 randomized
• Outcome measure was first attempt success at assigned method
  — Secondary measures- total number of attempts, time to successful access, time to first ACLS drug administration
Results

• Tibial IO 95% initial success rate, humeral IO 51%, PIV 43%
• Time to success was shortest for tibial IO
• Able to infuse 800 ml via PIV compared to 400 ml through either IO
IO vs IV in Out of Hosp Arrest

**Conclusions:**
- “tibial IO was most effective method of gaining vascular access in out of hospital arrest”
- Humeral IO less than optimal in arrest situations due to increased dislodgement

**Limitations**
- Numerous - significant amount of self reported data from EMTs
- Not blinded
- Humeral IO patients had higher BMI – likely confounded placement
- No outcomes data
• So…. Now that you have the IO in (probably quicker than you can get an IV or CVC), can you trust that the medications you are giving are getting to where they need to go and will have the same effect?
Comparison of Fluid Infusion Rates Among Peripheral Intravenous and Humerus, Femur, Malleolus, and Tibial Intraosseous Sites in Normovolemic and Hypovolemic Piglets

Study objectives: To compare infusion rates from various intraosseous sites (tibial, medial malleolar, distal femoral, and humeral) and at a peripheral IV site under gravity and pressure flow in normovolemic and hypovolemic states.

- 23 piglets, anesthetized and intubated
  - IO placed in femur, medial malleolus, tibia
- Mean infusion rates for each location with and without pressure bag.
- Change in flow rate with hypovolemia assessed by removing 30% of blood volume
• Average flow rates:
  – PIV 23.6 ml/min, humeral IO 22.3 ml/min, femoral IO 16.5 ml/min, medial mall IO 12.1 ml/min, proximal IO 8.8 ml/min

• Hypovolemia markedly decreased flow rates
  – Average flow 14.6 ml/min vs 21.5 ml/min
Randomized study of 22 patients with chronic cancer pain

- Patients served as own controls
- Iliac IO device placed, morphine was administered
  - Blood draws for morphine level drawn at various time points
- Similar process for IV morphine
• Similar T1/2, Cmax, AUC
• Only significant difference in Vd
  – Postulated to be due to medication deposition in bone near administration site

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intraosseous route (±SD)</th>
<th>Intravenous route (±SD)</th>
<th>Intraosseous/Intravenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUC_{(0–τ)} (ng min⁻¹ mL⁻¹)</td>
<td>3637 ± 1282</td>
<td>4047 ± 1540</td>
<td>0.90</td>
</tr>
<tr>
<td>AUC_{(0–∞)} (ng min⁻¹ mL⁻¹)</td>
<td>4372 ± 1785</td>
<td>4410 ± 1930</td>
<td>0.99</td>
</tr>
<tr>
<td>C_{max} (ng/mL)</td>
<td>235 ± 107</td>
<td>289 ± 197</td>
<td>0.81</td>
</tr>
<tr>
<td>T_{max} (min)</td>
<td>1.29 ± 0.469</td>
<td>1.36 ± 0.497</td>
<td>0.95</td>
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<tr>
<td>Cl (mL kg⁻¹ min⁻¹)</td>
<td>20.2 ± 7.62</td>
<td>20.6 ± 9.41</td>
<td>0.98</td>
</tr>
<tr>
<td>V_d (L/kg)</td>
<td>4.81 ± 1.66</td>
<td>3.62 ± 1.41*</td>
<td>1.33</td>
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<tr>
<td>V_{des} (L/kg)</td>
<td>3.49 ± 1.30</td>
<td>2.80 ± 1.20</td>
<td>1.25</td>
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<tr>
<td>ke (min⁻¹)</td>
<td>0.005 ± 0.004</td>
<td>0.006 ± 0.003</td>
<td>0.83</td>
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<tr>
<td>t_{1/2} (min)</td>
<td>140 ± 108</td>
<td>118 ± 56</td>
<td>1.19</td>
</tr>
</tbody>
</table>

* There was a significant greater V_d calculated after intraosseous infusion (P = .0247). There were no other statistically significant differences between the parameters for the intraosseous vs the intravenous administrations.

* Harmonic mean.
• Limitations
  – Morphine pharmacokinetics are not necessarily generalizable to other classes (i.e. code medications)
  – Patient had normal hemodynamics – not generalizable to code situation
  – 8 patients were excluded due to incomplete data collection (missed blood draws) – only able to extract data from 14
Comparison of tibial, sternal, and central venous drug administration during CPR in swine model

7 swine underwent anesthesia, had sternal, tibial IO placed and CVC in RIJ

– Vfib induced with KCl
### Table 1

Appearance times in seconds from injection to maximum tracer concentrations and half (50%) maximal concentration.

<table>
<thead>
<tr>
<th>Animal (n = 7)</th>
<th>Tibial IO vs. sternal IO injection</th>
<th>Peak concentration</th>
<th>50% Peak concentration</th>
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<tr>
<td></td>
<td>Sternum</td>
<td>Tibia</td>
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</tr>
<tr>
<td>86</td>
<td>80</td>
<td>110</td>
<td>36</td>
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<td>21</td>
<td>90</td>
<td>150</td>
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<td>22</td>
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<tr>
<td>SEM</td>
<td>11</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>CI</td>
<td>30–75</td>
<td>55–158</td>
<td>16–27</td>
</tr>
</tbody>
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CI, confidence interval (confidence level = 95%); SEM, standard error of the mean.

* p = 0.03 – peak concentration – sternal vs. sternum.

### Table 2

Appearance times in seconds from injection to maximum tracer concentrations and half (50%) maximal concentration.

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<td>IV</td>
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<tr>
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<td>50</td>
<td>36.4</td>
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<td>SEM</td>
<td>17</td>
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<tr>
<td>CI</td>
<td>64–129</td>
<td>45–94</td>
<td>28–42</td>
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* p = 0.17 – peak concentration – sternal vs. central venous infusion.

### Table 3

Dose delivered for tibial vs. sternal IO injections calculated as area under the curve for aortic concentration µg/ml divided by dose injected (mg) over 480 s after injection. The relative effectiveness of the two routes is shown as a ratio of the area under the curve (AUC), tibial IO divided by sternal IO.

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<th>Relative dose delivered of tracers (Tibial IO vs. sternal IO injection—AUC_{0–480})</th>
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<tr>
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<td>21</td>
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<td>CI</td>
<td>564–789</td>
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* p = 0.003 – comparison between AUC_{0–480} – tibial vs. sternum.

### Table 4

Dose delivered for sternal IO versus central venous IV injections calculated as area under the curve for aortic concentration µg/ml divided by dose injected (mg) over 480 s after injection. The relative effectiveness of the two routes is shown as a ratio of the area under the curve (AUC), sternal IO divided by central venous IV.

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<td>CI</td>
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p = 0.22 – comparison between AUC_{0–480} – sternal vs. central venous infusion.

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Appearance times in seconds from injection to maximum tracer concentrations and half (50%) maximal concentration.

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Dose delivered for tibial vs. sternal IO injections calculated as area under the curve for aortic concentration μg/ml divided by dose injected (mg) over 480 s after injection. The relative effectiveness of the two routes is shown as a ratio of the area under the curve (AUC), tibial IO divided by sternal IO.

| Relative dose delivered of tracers (Tibial IO vs. sternal IO injection—AUC0–480s) |
|----------------------------------------|----------------------------------------|
| Animal                                | AUC (μg/ml) | Ratio |
|                                       | Sternum   | Tibia | Tibia/sternum |
| 21                                    | 912       | 450   | 0.49          |
| 18                                    | 776       | 382   | 0.49          |
| 34                                    | 601       | 400   | 0.67          |
| 35                                    | 645       | 368   | 0.71          |
| 39                                    | 509       | 423   | 0.83          |
| 36                                    | 511       | 418   | 0.82          |
| 86                                    | 783       | 545   | 0.70          |
| Mean                                  | 677       | 427   | 0.65          |
| SEM                                   | 57        | 22    | 0.05          |
| CI                                    | 564–789   | 383–470 | 0.6–0.7      |

CI, confidence interval (confidence level = 95%); SEM, standard error of the mean.

### Table 4
Dose delivered for tibial IO versus central venous IV injections calculated as area under the curve for aortic concentration μg/ml divided by dose injected (mg) over 480 seconds after injection. The relative effectiveness of the two routes is shown as a ratio of the area under the curve (AUC), sternal IO divided by central venous IV.

| Relative dose delivered of tracers (sternal IO vs. central venous IV injection—AUC0–480s) |
|----------------------------------------|----------------------------------------|
| Animal                                | AUC μg/ml | Ratio |
|                                       | IV        | Sternum | Sternum/IV |
| 89                                    | 694       | 589     | 0.85       |
| 105                                   | 855       | 939     | 1.10       |
| 95                                    | 879       | 805     | 0.92       |
| 110                                   | 854       | 783     | 0.92       |
| 92                                    | 956       | 923     | 0.97       |
| 87                                    | 934       | 385     | 0.41       |
| Mean                                  | 862       | 737     | 0.86       |
| SEM                                   | 38        | 87      | 0.10       |
| CI                                    | 788–935   | 566–907 | 0.7–1.0    |

CI, confidence interval (confidence level = 95%); SEM, standard error of the mean.

*p = 0.17 – peak concentration – sternum vs. central venous infusion.

*p = 0.06 – 50% peak concentration – sternum vs. central venous infusion.

Cl, confidence interval (confidence level = 95%); SEM, standard error of the mean.
Results

• Similar drug delivery for sternal IO and CVC route
  – Time to peak 97 sec vs. 70 sec (p=0.17)
  – Total dose delivered similar but slightly decreased in IO – approx 86% of CVC dose (p=0.22)

• Tibial IO vs sternal IO
  – Faster with sternal IO – time to peak 53 sec vs 107 sec (p=0.03)
  – Dose delivered from tibial was 65% of sternal route (p=0.003)

• Conclusion: either route is adequate for CPR drug delivery as peak concentrations were attained in less than 2 min via either route, may need dose adjustment for tibial route...?
Limitations

• Swine model
  – CPR is different in pigs due to anatomic differences
  – Tibia is shorter and closer to central circulation
  – Used young and healthy animals

• Did not actually measure epi concentrations
  – Used 2 types of dye mixed with epi, measured dye concentrations as surrogate
Laboratory Investigations

Pharmacokinetics from multiple intraosseous and peripheral intravenous site injections in normovolemic and hypovolemic pigs

David W. Warren, MD, FRCP; Niranjan Kissoon, MD, FCCM; Adel Mattar, MD, FRCP; Gary Morrissey, MSc; Denis Gravelle, RTMM; Michael J. Rieder, MD, FRCP

- Comparison of IO sites (femur, tibia or medial malleolus, and proximal humerus) with 22 ga IV established in front leg
- NaBicarb and pharmacokinetic tracers introduced, art blood samples from carotid used to assess increase in radioactivity, EtCO2 trended (used as surrogate for NaBicarb) and allowed to stabilize
- Studies done in normovolemic conditions, then 30% of blood volume was removed and injections repeated in all access sites
• Slightly longer time to maximal increase in EtCO2 from medial malleolus, other sites not statistically significant difference

• Longer time to central circulation from all sites with hypovolemia

• **Conclusion**: difference in time to central circulation was statistically significant for hypovolemia or use of medial malleolus, but likely not clinically significant.
Limitations

• Swine based. Again.
• Model did not have “code” situation
  – Pigs were anesthetized but had otherwise normal circulation for normovolemic studies
• Anesthesia may alter pharmacokinetics of sodium bicarbonate
• 6 newborn lambs had lines placed and were given infusions of epinephrine
  – femoral CVC, IO, arterial line (used for sampling)
  – Infusions given by either IO or CVC, repeated in >48 hours between trials
• Normovolemic, not anesthetized - only local used
• Epinephrine given in continuous graded infusion
  – 0.5, 1.0, 2.5, 5.0 ug/kg/min
• Vitals recorded, serial plasma epinephrine levels drawn during infusions
• No difference in plasma epinephrine concentrations
• IO required slightly higher concentration to induce hemodynamic changes (4.0 +/- 0.9 ng/ml vs 2.0 +/- 0.6 ng/ml)
• **Conclusions**: no temporal difference between IO and CVC, but may need higher dosing in IO to achieve same effect
Limitations

• Animal model (again)
• Small sample size
• Not a code situation, animals had presumably normal hemodynamics
• Used continuous infusions, not push dose epinephrine
• Review of human and animal studies available on from 1950-2007
• Most studies are case reports, animal based experiments, few case series
• All code drugs (epinephrine, amiodarone, atropine, calcium, bicarb), most intubating meds (succinylcholine, etomidate, rocuronium, versed)

• Antibiotics and dilantin may need dose adjustment
  – And possibly epi?
But wait, there’s more!

Rapid and Complete Bioavailability of Antidotes for Organophosphorus Nerve Agent and Cyanide Poisoning in Minipigs After Intraosseous Administration

Douglas B. Murray, MBChB, Michael Eddleston, PhD, Simon Thomas, MD, Robert D. Jefferson, MBBS, Adrian Thompson, BSc, Mick Dunn, PhD, Daniel S. Vidler, PhD, R. Eddie Clutton, BVSc, and Peter G. Blain, PhD

INTRAOSSEOUS ADMINISTRATION OF THROMBOLYTICS FOR PULMONARY EMBOLISM

Taylor R. Spencer, MD, MPH

Intraosseous Lipid Emulsion: An Effective Alternative to IV Delivery in Emergency Situations

Michael Robert Fettiplace, MS, PhD; Richard Ripper, CVT; Kinga Lis, BS; Douglas L. Feinstein, PhD; Israel Rubinstein, MD; Guy Weinberg, MD

SUCCESSFUL COMPUTED TOMOGRAPHY ANGIOGRAM THROUGH TIBIAL INTRAOSSEOUS ACCESS: A CASE REPORT

Kerry L. Ahrens, MD, MS; Scott B. Reeder, MD, PhD; Jon G. Keevil, MD; and Janis P. Tupper, MD
Not so fast...

Intraosseous Infusion Is unreliable for Adenosine Delivery in the Treatment of Supraventricular Tachycardia

Ian Scott Goodman, MD, CM*† and Christina Jennifer Lu, BS†

- 2 case reports of failure of adenosine in pediatric patients
- Patients converted with adenosine once CVC placed

• Debate over blood product administration – so far no research and only a few editorials published
  - Concern that increased pressure in bone may lead to hemolysis
IO Complications

• Overall very safe with few complications
• Most common complication is extravasation and/or dislodgement
  – Risk increases the longer the device is left in place, if device is not properly placed (in subperiosteum), or if multiple attempts are made in same bone
• Infection (e.g. osteomyelitis) relatively UNCOMMON
• Other complications frequently cited – skin/tissue necrosis, fat/air emboli, fractures, concern for growth plate damage
• Literature review
  – 30 studies encompassing 4270 cases
• Overall complication rate very low
  – 2.1% (n=89) “failed infusions”
  – 0.8% (n=37) with complications – 0.6% (n=27) developed osteomyelitis
    • Generally occurred in patients with IO devices left in place for more than 24 hours or who were bacteremic at time of placement
  – Low rates of fat embolism – thought to be due to low fat content in pediatric bone marrow
• Prospective trial to assess ability of EMTs to become proficient in IO usage
• 152 patients, 162 IO attempts
• Overall complication rate of 12% (n=14)
  – All were due to infiltration of line
  – Infiltration is considered a “minor complications” BUT... may be more significant as it may cause compartment syndrome, tissue sloughing or necrosis – leading to need for surgical intervention/amputation
• IO infusions into normotensive dogs – used various code medications or saline placebo
• Lungs removed during subsequent autopsy – sectioned to assess for fat or bone marrow emboli
• Emboli found in ALL lung specimens – burden varied from 0.11 to 4.48 emboli/mm²
• No significant difference noted in PaO₂ during ventilation for 4 hours after, no evidence of shunting
• Limitations:
  – Experiment was time limited – complications may develop later
  – No CPR was done on dogs – may increase risk for larger or clinically significant emboli
  – No animal had intracardiac (R→L shunt)
Future of Intraosseous Lines?

• May be able to use IO as alternative to conventional arterial line
Conclusions

• IO is a viable, proven method of establishing emergent access in critically ill patients

• Pharmacokinetics are (in general) similar to medications given IV
  – May need dose adjustment in code dose for epinephrine
  – Don’t use adenosine

• Complications are generally less serious
  – More research needed re: fat embolism risk

• May eventually be able to use for hemodynamic monitoring
Final Thought

Successful cardiopulmonary resuscitation following cardiopulmonary arrest in a geriatric chinchilla

Christina M. Fernandez, DVM; Jamie L. Peyton, DVM, DACVECC; Mona Miller, DVM; Eric G. Johnson, DVM, DACVR and Jan P. Kovacic, DVM, DACVECC

Intraosseous lines save lives.
QUESTIONS???