Title: Intraosseous vascular access in adults – a review of contemporary practice

Abstract

Aim & objectives. This literature review aim is to present a detailed investigation critiquing contemporary practices of intraosseous vascular access in adult patients. Specific objectives identified led to the exploration of clinical contexts, IO device/s and anatomical sites; education and training requirements; implications and recommendations for emergency healthcare practice and any requirements for further research.

Background. The intraosseous route is an established method of obtaining vascular access in children in acute and emergency situations and is now increasingly being used in adults as an alternative to intravenous access, yet a paucity of evidence exists regarding its use, effectiveness and implementation.

Search strategies. An exploratory literature review was undertaken in acknowledgement of the broad and complex nature of the project aim. Five electronic search engines were examined iteratively from June 2013 to February 2014. The search terms were ‘intraosseous’ AND ‘adult’ which were purposely limited due to the exploratory nature of the review. Studies that met the inclusion criteria of primary research articles with adult focus, paediatric lead research were excluded. Primary research international also included. Secondary research, reviews, case reports, editorials and opinion papers were excluded.

Conclusion. Intraosseous vascular access is considered an alternative vascular access route although debate considering the preferred anatomical site is ongoing. Documented practices are only established in pre-hospital and specialist Emergency Department settings, however variety exists in policy and actual practice. Achieving insertion competence is relatively uncomplicated following minimal preparation although ongoing skill maintenance is less clear. Intraosseous vascular access is associated with minimal complications although pain is a significant issue for the conscious patient especially during fluid administration.

Relevance to clinical practice. The intraosseous route is clearly a valuable alternative to problematic intravascular access. However further research, including cost effectiveness reviews, is required to gain clarity of whole acute care approaches.

Keywords:

Advanced Life Support

Drug administration

Intraosseous

Nursing

Resuscitation

Vascular Access

INTRODUCTION

The 2010 Resuscitation Guidelines published simultaneously by the American Heart Association (AHA) (Neumer *et al*. 2010), the European Resuscitation Council (ERC) (Deakin *et al*., 2010) and the Resuscitation Council, United Kingdom (RCUK, 2010) included an increased recommendation for the use of the intraosseous (IO) route for administration of drugs and fluids if intravenous (IV) access could not be established. Although the use of IO access was presented in previous guidelines (Nolan *et al*., 2005, RCUK, 2005), the inclusion of IO access as an alternative to IV access in the adult Advanced Life Support algorithm itself suggests a higher profile for the use of this route in adult resuscitation. This paper therefore examines the use of the IO route in critically ill adults.

Background

For many critically ill patients early IV access in emergency situations is vital, and any delays could have a significant impact on the chance of survival (Fenwick, 2010, Hartholt *et al*., 2010, Schalk *et al.*, 2011). Intravenous (IV) has been the conventional route of choice (Gazin *et al.*, 2011) but securing access in the emergency situation can be a challenging process (Day, 2011, Ong *et al*., 2009a, Shalk *et al*., 2011). IO provides a reliable alternative (Shalk *et al*., 2011).

Paxton (2010) and Weiser *et al*. (2012) detail the development of the IO route, including its first use in animal studies in the 1920s to the introduction to humans in the mid-1930s and the development of Paediatric Life Support practices during the early 1980s, which promoted IO access as a method of obtaining intravascular access for paediatric patients.

The AHA suggest that IO should be considered in adults if “IV access is not readily available” (Neumer *et al*., 2010, p. S742) whilst the ERC guidelines suggest that the IO route is considered if “intravenous access is difficult or impossible” (Deaking *et al*., 2010, p 1314). The RCUK (2010, p. 73) offer some

additional criteria suggesting that “if intravenous access cannot be established within the first two minutes of resuscitation, consider gaining IO access”.

The suggested sites for insertion of the IO device are usually limited to the proximal tibia, the distal tibia, the proximal humerus and the sternum. Factors that affect the choice of site include the age and/or size of the patient, any contraindications related to a particular site, the device of choice and the skills of the operator (Fenwick, 2010). The proximal tibia is advantageous in resuscitation as it has easily identifiable landmarks, has a relatively thin cortex, and is distant from other likely resuscitative efforts (Ong *et al*., 2009a, Luck *et al.,* 2010. Wampler *et al*. (2012) suggest that the proximal humerus may be more difficult to access than some of the other suggested sites, not least because of an excess in overlying tissue in some patients leading to difficulties in identifying the correct anatomical landmarks (Day, 2011, Leidel *et al*., 2010, Paxton, 2012) but that the attraction of this site is its close proximity to the central circulation.

Devices

Several devices are registered and available for use and are summarised in table 1.0.

THE REVIEW

Aims & Objectives

The scope for this literature retrieval and review is to explore current practices and associated contextual issues related to the use of IO access in critically ill adult patients. The review purpose being is to inform recommendations for clinical practice with this time-critical patient group in this emerging emergency intervention. The following objectives afford context and structure for the review:

- Explore clinical context where IO access practices are employed and the criteria/indications guiding its implementation.
- Investigate IO device/s and anatomical sites deemed most effective.
- Review the education and training required for initial and ongoing competence for IO access and management.
- Identify any implications and recommendations for emergency healthcare practice and further research.

Search methods

Comprehensive searches were conducted utilising the databases CINAHL Plus with full text, Medline, the Cochrane library, SUMMON and PUBMED. The databases were examined using specific key word combinations, including Intraosseous AND access AND adult. Keywords were purposely limited due to the exploratory nature of the review.

Inclusions/exclusion criteria

Full text papers from January 2008 to December 2013 were included. Primary research articles were included if the focus was adult not paediatrics. International research was included although had to be accessible in English. Primary research was included providing detailed, valid and transparent processes and outcome measures were articulated. Randomised controlled trials (RCTs), quasi-experimental and non-experimental prospective study designs as well as retrospective cohort analysis were shortlisted. Secondary research, reviews, case reports, editorials and opinion papers were excluded.

Search outcomes are summerised in table 2.0. The evidence quality critique was structured in a style advocated by Polit and Beck (2014) appraising methodological details for interpretation. Subsequently themes were established guided by the research aim and questions. Results were extracted and scrutinised for significance in order to draw conclusions and make subsequent recommendations.

RESULTS

International research was retrieved from Europe (n=10), Singapore (n=2) the USA (n=6) and USA and Brazil combined (n=1). The final nineteen research papers were all quantitative or incorporated mixed data collection approaches. Two undertook a retrospective view of IO practices including Sunde *et al.*'s (2010) seven year case notes review and Wampler *et al.*'s (2012) retrospective cohort analysis, although they collected data prospectively. Of the studies that were wholly prospective in design, Brenner *et al.* (2008), Hartholt *et al.* (2010), Leidel *et al.* (2010), Leidel *et al.* (2012) and Reades *et al.* (2011b) were experimental RCTs. Reiter *et al.*'s (2013) observational study utilised randomised experimental scenarios. Lamhaut *et al.*(2010), Levitan *et al.*(2009) and Philbeck *et al.* (2010) were quasi-experimental whilst Gazin *et al.* (2011), Molin *et al.* (2010), Ong *et al.* (2009a), Ong *et al.* (2009b), Reades *et al.* (2011a), Santos *et al.* (2013) and Schalk *et al.*(2011) were all non-experimental quantitative studies. As a result of analysis the following themes were identified and deemed significant areas of relevance.

Environment

Five of the studies were simulated experiments using a mix of cadavers (Brenner *et al.*, 2008, Levitan *et al.*, 2009), manikins (Lamhaut *et al.*, 2010, Reiter *et al.*, 2013) and bone (Ong *et al.*, 2009b). Two studies were undertaken in laboratory settings using voluntary participants (Philbeck *et al.*, 2010) or anaesthetised swine (Hoskins *et al.*, 2012). Significantly for IO practice, the majority of the other studies (n=8) were set in out of hospital environments (Gazin *et al.*, 2011,

Hartholt *et al.*, 2010, Reades *et al.*, 2011a, Reades *et al.*, 2011b, Santos *et al.*, 2013, Schalk *et al.*, 2011, Sunde *et al.*, 2010, Wampler *et al.*, 2012). Four were based in Emergency Departments (ED) (Leidel *et al.*, 2010, Leidel *et al.*, 2012, Molin *et al.*, 2010, Ong *et al.*, 2009a). No other clinical environments were included in the research selected.

Device

Many IO access devices are currently registered for use. The studies that undertook comparative research on the efficacy of IO devices include Hartholt *et al.* (2010) who randomised Jamshidi®, B.I.G™ and FAST1®. All three were considered user friendly and there was no significant difference with associated complications. The less costly Jamshidi® was significantly faster to insert (91%) than B.I.G™ (51%) and FAST1® (89%). Issues emerged regarding the complexity of FAST1® in the associated number of parts to assemble. Hartholt *et al.* (2010) did recognise the increasing popularity of EZ-IO®, though the device was not evaluated in their research. Leidel *et al.* (2010) compared EZ-IO® and B.I.G™ reporting slightly faster first attempt access with EZ-IO® but no statistical significance could be attributed (overall 85% first success and both performed within two minutes). Sunde *et al.'s* (2010) seven year retrospective analysis used B.I.G™ between 2003 and 2006 and EZ-IO® from 2006 onwards for adult patients. Insertion success rates were reportedly 55% for B.I.G™ and 96%, for EZ-IO®. All reported consistently over the period of the study.

The EZ-IO® battery operated power driver affords increased ease of insertion, even into thicker cortical bone (Gazin *et al.*, 2011, Wampler *et al.*, 2012). Brenner *et al.* (2008) found the ease of use and first attempt insertion of experienced practitioners, but with no IO experience to be significantly increased when using the battery operated EZ-IO® (97.8%) in comparison to the manually operated IO (79.5%) device on cadavers. Ong *et al.* (2009a) and Schalk *et al.* (2011) confirmed the ease of access with high first attempt insertion rates using the EZ-IO® (96% and 97% respectively). Gazin *et al.* (2011) reported a slightly lower

percentage on first insertion (84%) but a 97% successful insertion on second attempt. In the study by Schalk *et al.* (2011) participants indicated that they were 'very satisfied' with the EZ-IO® in terms of ease of use, and Molin *et al.'s* (2010) survey highlighted that 95% of Danish EDs favoured the EZ-IO®. Indeed the EZ-IO® was the most commonly used device in the adult population of the studies included in this review (Brenner *et al.*, 2008, Gazin *et al.*, 2011, Lamhaut *et al.*, 2010, Levitan *et al.*, 2009, Ong *et al*., 2009a, Ong *et al*., 2009b, Philbeck *et al.*, 2010, Reades *et al.*, 2011a, Reades *et al.*, 2011b, Reiter *et al.*, 2013, Santos *et al.*, 2013, Schalk *et al.* 2011, Sunde *et al.*, 2010, Wampler *et al.*, 2012).

Policy and Practice

Although IO access is often prescribed as first line management for children (Gazin *et al.* 2011), adult protocols in the main seemed to be driven by the failure of peripheral intravenous attempts, often as a result of two failed attempts in cardiac arrest or with patients that require advanced resuscitation procedures (Gazin *et al.*, 2011, Hartholt *et al.*, 2010, Ong *et al.*, 2009a, Santos *et al.*, 2013). Other papers provided slightly different instructions i.e. four failed attempts in adults with spontaneous cardiac activity (Gazin *et al.*, 2011) or peripheral access having been attempted three times or for a maximum of two minutes (Leidel *et al.*, 2010, Leidel *et al*., 2012) or 90 seconds (Ong *et al.*, 2009a).

Updates to patient care protocols for out-of-hospital cardiac arrest described by Reades *et al.* (2011a, 2011b) specified that every patient in cardiac arrest should receive an IO line for initial vascular access. During the study by Hartholt *et al.* (2010), IO access was attempted following two failed attempts at gaining intravenous access, or when cardiopulmonary resuscitation was required. Schalk *et al.* (2011) considered decision making for IO access to be at the sole discretion of the practitioner resulting in IO being used for primary vascular access in 14% (n=10) of insertions and after failed venous access in 86% (n=64). Molin *et al.*'s (2010) review of IO use in Denmark, found 58% (n=11) of Emergency Departments (EDs) had no local guidelines to inform IO access.

Significantly, one third of their participants were aware of one or more incidents where IO was indicated but not established indeed, the study highlighted that in many EDs IO access was not used at all and where it was used national guidance was not followed.

Insertion

Leidel *et al.* (2012) concluded that the IO is six minutes faster and easier to achieve than central vascular access (85% IO to 60% Central venous catheter first attempt success). The IO route also requires less training and has fewer associated complications. Reiter *et al.* (2013) reported that the mean time to vascular access using EZ-IO® compared to Central venous catheter was significantly faster (49.0 seconds compared to 194.6 seconds respectively) in simulated cardiac arrest. Ong *et al.* (2009a) recorded speeds of IO vascular insertion to be significantly faster (within 20 seconds) than peripheral vascular access.

Hoskins *et al.* (2012) compared a) tibia and sternum IO routes and b) sternum and central venous routes in pigs and, whilst finding no significant difference in the pharmokinetics in the second group, they suggest IO is an effective, non-collapsible means of drug delivery. Ong *et al.* (2009a) found no significant difference between tibial and humerus IO insertion sites although they further suggest that the ideal IO insertion site should be a long bone with easily identifiable, superficial landmarks and conclude that the proximal tibia is the first choice with proximal humerus second. Leidel *et al.* (2010, 2012) and Wampler *et al.* (2010) recommend the use of the humeral head for IO access in cardiac arrest. Both suggest alternatives may be chosen if the situation dictated i.e. appropriate to injury pattern or condition. Of Leidel *et al.*'s (2012) 40 participants, 22 accessed the humeral head and 18 the proximal tibia. The proximal humerus was used during the study by Wampler *et al.* (2012) and was attempted in 61% (n=247) of cardiac arrests, with 91% (n=224) successful placement on first attempt and 94% (n=232) by the second attempt. Obesity was reported to be the

primary cause of insertion failure (n=4) and in 2% (n=4) subsequent dislodgment was documented during the resuscitation or during transport. Although the study aim was to evaluate the success rate of humeral head placement, Wampler *et al*, (2012) also reported that the tibia (exact site not stated) was accessed on a further 161 patients with first and second attempt success rates of 95% and 98% respectively.

Reades *et al.*'s (2011a) comparison of first attempt success by paramedics during out of hospital cardiac arrests (n=88) reported significantly increased first attempt success with the tibia (89.7%) in comparison with the humerus (60%). They also reported increased needle dislodgement in the humeral location. In a follow up study Reades *et al.* (2011b) compared the initial two IO sites with peripheral intravenous route and concluded that first attempt success rate for proximal tibial insertion of an IO was significantly higher ($p< 0.001$) than either the humeral or peripheral intravenous routes. Once again, they also identified an increased risk of dislodgement in the humeral site.

Molin *et al.*'s (2010) survey of 19 EDs in Denmark highlighted that 84% (n=16) recommended/preferred the tibial site, a further 10% (n=2) the humerus and medial malleolus with 5% (n=1) indicating no preference. Fifty-nine percent of insertions reviewed by Sunde *et al.* (2010) were in the proximal tibia and only 3.8% in the humerus, with 37% not recorded. The anterior proximal tibia was the preferred site with Santos *et al.*'s (2013) cohort (98%, n=59) with only one insertion in the humeral head. Similarly in Schalk *et al.'s* (2011) study all participants chose either the proximal (n=75) or distal (n=2) tibia. Reades *et al.'s* (2011b) paramedic cohort highlighted preference for the tibial route and felt 'less comfortable' with the IO access via the humeral site.

Preparation

Practically all of the studies prepared the participants prior to their involvement in IO practice and/or their research (Hartholt *et al.*, 2010, Ong *et al.*, 2009a, Sunde

et al., 2010). Many specified training consisting of one hour lecture/didactic instruction with further time allocated for hands on practice (Gazin *et al.*, 2011, Lamhaut *et al.*, 2010, Leidel *et al*., 2010, Leidel *et al.*, 2012, Santos *et al.*, 2013). Brenner *et al.* (2008) considered a 45 minute lecture and 15 minute demonstration to be sufficient and although no time was specified, Ong *et al.* (2009b) provided instructions on use of the EZ-IO® and observed an insertion demonstration on a bone model before study data was gathered.

Wampler *et al.*'s (2012) cohort of paramedics who had previous experience of IO insertion received 1.5 hours of didactic and hands-on instruction, but significantly were evaluated on their cognition and techniques. Competence assessment was also highlighted by Hartholt *et al.* (2010) and Reades *et al.* (2011a, 2011b) with all participants requiring proficiency to be demonstrated prior to completion of their IO training.

Gazin *et al.* (2011) suggested that IO access practice required only short learning curves even with novice operators. Levitan *et al.* (2009) confirmed this hypothesis that minimal training consisting of five minutes briefing and a single demonstration, resulted in speedy and successful IO insertions on cadavers. Their research trialed the EZ-IO® and the participants were Emergency Care Practitioners, 80.8% of whom had never placed an IO needle and 100% of whom had not used EZ-IO® previously. The study identified a 97.3% success on first attempt (n=297).

Repeat training was reported by Schalk *et al.* (2011) consisting of 15 minutes 'hands-on' manikin training on an annual basis. In addition to the initial training Hartholt *et al.* (2010) provided special instructions, training sets were available at the station and training was repeated after one year. Wampler *et al.* (2012) made a video available for reference. Eleven out of 19 (58%) of EDs in Denmark offered no training on the use of IO devices (Molin *et al.* 2010)

Practitioner

The participants were experienced practitioners working in pre-hospital or hospital emergency care settings (Gazin *et al.*, 2011, Hartholt *et al.*, 2010, Leidel *et al.*, 2010, Ong *et al*., 2009a, Santos *et al*., 2013, Schalk *et al.*, 2011, Sunde *et al.*, 2010), paramedics and nurses (Gazin *et al.*, 2011, Reades *et al.*, 2011a, Reades *et al.*, 2011b, Schalk *et al.*, 2011, Wampler *et al.*, 2012). Molin *et al.*'s (2010) survey explored whose responsibility it was to obtain IO access. A high number of responders (78%) specified anaestheologist and none of them expected that the device would be handled by anyone below specialist physician level.

Complications/issues

Complications for IO vascular access were reported throughout the studies as rare and mostly minor. Gazin *et al.'s* (2011) sample of 39 and Leidel *et al.'s* (2010) sample of 20 each reported one local transient inflammation event per sample. Of the 6% of failed insertion attempts identified by Wampler *et al.* (2012) using the humerus, 50% of those where the cause was documented were attributed to the obesity of the patient. Reades *et al.* (2011a) suggested that increased needle dislodgement in the humeral location is likely to be attributed to activity during cardiac arrest occurring around the upper torso.

The most significant issue for conscious patients with an IO device in situ was their experience of pain. Ong *et al.* (2009a) recommend that 20-50mg Lidocaine 2% was administered to all conscious patients, although the effectiveness of this was not evaluated. Schalk *et al.'s* (2011) study involved 22 conscious patients and it was reported that, without anesthetic, none of the patients described the insertion as painful. However in Gazin *et al's* (2011) study, 18 patients did complain of pain upon fluid administration, particularly during the initial 20ml flush despite being given analgesia. Philbeck *et al.* (2010) evaluated pain following insertion and infusion. Despite their highlighted limitation of using healthy

volunteers, they concluded that the participants experienced less pain in the proximal humeral site compared with each tibial site.

Individual devices presented some issues. Hartholt *et al.* (2010) found that two Jamshidi® needles bent during insertion. In addition Hemostat was required on five occasions to remove the needle trocar following insertion of B.I.G™ and on two occasions there was no cortex penetration; this finding also being reported on four occasions using the tibial site by Leidel *et al.* (2010). On five occasions Leidel *et al.* (2010) identified that the stylet became stuck and was only able to be removed with a clamp. Once removed however, no other complications were observed. Ong *et al.* (2009a) reported no complications, yet on two occasions staff reported difficulty removing the needle. Both were removed successfully once the correct technique was applied.

Reades *et al.* (2011b) was the only author to raise the issue of cost. The cost for IO access, specifically the needles, is significantly greater than peripheral intravenous equipment. They recommended that further studies were required to quantify the cost effectiveness of IO practice.

Indications

The main clinical indications for use of IO access tended to be cardiac arrest, as in Reades *et al*. (2011) and Wampler *et al.* (2011). Gazin *et al.* (2011), Hartholt *et al.* (2010), Santos *et al.* (2013) and Schalk *et al.* (2011) did report on practices for IO access with patients with spontaneous circulation however difficulties occurred in the interpretation and comparison of results due to inconsistency in term presentation. Some examples include high energy trauma (20%), myocardial ischaemia (7%) or drug poisoning (5%) (Schalk *et al.*, 2011) coma, shock (Gazin *et al.*, 2011) or attempted suicide (8%) (Hartholt *et al.*, 2010).

Follow up

Minimal follow up information was available throughout most of the studies. Leidel *et al.*, (2012) indicated that the IO device was removed after 24 hours and 14 days of follow up data was collected yet this was not discussed. Sunde *et al.* (2010) reported that of the 70 patients (adult and child), 40 (57%) survived to hospital admission, whilst only 12 (17%) survived to discharge. Sunde *et al*. (2010) also reported that only 50% of patients received prophylactic antibiotics, despite this being a recommendation in local guidelines. They also reported that IO needles were removed within two hours of admission in seven patients but the remaining cases were not documented. No cases of osteomyelitis or other serious complications were recorded. Of Santos *et al.*'s (2013) adult and child cohort (n=58), 22 survived at 48 hours (38%) and 17 were discharged from hospital (29%) with no IO complications reported.

Interestingly, despite data collection taking place over an 18 month period in a busy urban trauma centre with over 35,000 presentations per year, Leidel *et al*. (2012) only recruited 40 eligible participants. Similarly Sunde *et al.*'s (2010) seven year pre-hospital retrospective analysis, albeit before guideline changes, identified 78 insertion attempts on 70 patients, highlighting the limited documented use of IO access in adults within current clinical practice.

DISCUSSION

All clinical studies included in this review were undertaken in either emergency department trauma centres or pre-hospital emergency care. IO practice in other emergency and critical care settings therefore is presumed to be more limited although further research is required to investigate this.

Although minimal issues were associated with all IO devices, the EZ-IO® was the most popular and consistently used device in the adult population across the studies reviewed, and is relatively simple to use following minimal preparation. Ongoing competence outcomes and actual immediate response when faced with the situation however remains debatable. Cost is also a significant issue and may

influence the choice of device. Clear analysis of quality and cost effectiveness is required.

Many policies indicate that IO access should be attempted after two failed peripheral intravenous catheter insertions for patients in cardiac arrest. This does lead to an inevitable delay in obtaining vascular access. It could be argued that experienced clinical practitioners leading care for critically ill patients should be able to determine the high risk group of patients with challenging venous access that would benefit from primary IO access to prevent any further delays in obtaining crucial vascular access.

Although, the proximal humerus route is recommended when using EZ-IO®, tibial access occurred more frequently and was considered easier and faster by practitioners, being associated with less dislodging and fewer unsuccessful attempts compared with other sites. It was suggested that the proximal humerus site should also be strongly considered for optimal infusion and easier pain control (Philbeck *et al.* 2010) therefore ongoing monitoring of this is required.

The research consistently reported that the IO insertion procedure was practical for emergency care practitioners, although the review provided minimal discussion on the issues associated with continued use, ongoing management and subsequent removal of the device once the clinical need is ended. IO access does seem to be associated with minimal reported complications although only limited long term data was available. Pain is the significant issue for conscious patients although interestingly not on insertion but on administration of fluids/flush through the cannula; therefore Lidocaine would appear to be an absolute necessity following insertion.

Limitations

Although recurrent searches were undertaken, it is acknowledged that some studies may not have been identified due to inaccessibility. They may not have

been identified as their primary research intentions were not on adult IO access, therefore impacting on the comparison of the results.

CONCLUSION

IO practice is evidently developing and becoming established as a viable option for vascular access within adult critical care and stands to make an important contribution to vascular access. Further exploration is however required to gain a clearer understanding of IO contributions to increased positive outcomes following resuscitation attempts not only within pre-hospital and EDs but also across all critical care specialties.

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