Table 1.0 Summary of IO devices

Device	Manufacturer	Other information
First Access for Shock and Trauma 1 (FAST1®)	PYNG Medical, Richmond, Canada	The FAST1® is the only device currently approved by the FDA for use on the sternum (Day, 2011, PYNG Medical, 2010). It is designed to be inserted into the manubrium (the upper third of the sternum) and consists of an introducer, which houses several stabiliser points and an infusion tube. It relies on operator force i.e. it is not battery operated, pneumatic or spring loaded (PYNG Medical 2010). Downward pressure on the introducer pushes the infusion tube through soft tissue and into the sternum. When the steel tip of the infusion tube is in the marrow, it automatically separates from the introducer which can then be removed (Day, 2011, PYNG Medical, 2010).
EZ-IO®	Vidacare Corporation, San Antonio, Texas, USA	The EZ-IO® system consists of a battery operated small, hand-held power driver, a needle set and connectors (Day, 2011, Vidacare, 2014a). Three sizes (length) of needle are currently available. The power driver is reusable (approx. 500 insertions), containing a sealed lithium battery (Vidacare, 2014b). Recommended sites for insertion are the proximal humerus, the proximal tibia and the distal tibia. Each needle has a black line 5mm from the hub and this is used to help check selection of the correct needle length prior to insertion. The longer needles have additional lines marked every centimetre from the first. The needle is inserted through the skin until it touches bone. At least one black line must be visible above the skin before drilling begins. If not, the needle is removed and a longer one inserted instead. If a black line is visible, the needle can safely be inserted by pressing the trigger on the power driver and applying gentle, consistent, steady downward pressure until the hub of the needle is almost flush with the skin.
Bone Injection Gun (B.I.G™)	Waismed Ltd, Houston, Texas, USA	Introduced in 2000 as the world's first automatic IO device (Waismed, 2009) the B.I.G™ is a spring-loaded device that delivers the trocar and a needle directly into the bone. The trocar is then removed leaving the needle in situ. The B.I.G™ is colour coded, signifying sizes appropriate for use in adult and paediatrics, with a third option available for veterinarians (Day, 2011). Suggested insertion sites are the proximal tibia and the proximal humerus (Waismed, 2008).
Cook Needle	Cook Medical Inc, Bloomington, Indiana, USA	A manual device that is likely to be familiar to many emergency nurses (Fenwick, 2010). Although this device has been used for adults (Brenner *et al*., 2008, Molin *et al.*, 2010), product information from Cook Medical (2014) would indicate that it is recommended for use in paediatric emergencies.
Jamshidi® needle	CareFusion, San Diego, California, USA	The Jamshidi® needle is primarily a bone marrow biopsy needle (CareFusion, 2014), but has been used for IO access (Hartholt *et al*., 2010, Hoskins *et al*., 2012).

Table: 2.0 Anatomy & Physiology

Paxton (2012, p. 200) states that "…for the purposes of IO infusion, the 'intraosseous space' is generally defined as that space within both the cancellous bone of the epiphysis and the medullary cavity of the diaphysis, which is in continuity". The diaphysis (or shaft) of a typical long bone (so called because of their elongated shape, not their overall size – Marieb & Hoehn, 2013) consists of a narrow medullary cavity covered by a relatively thick layer of cortical, or compact bone (Marieb & Hoehn, 2013, Paxton, 2012,). The epiphysis (the bone ends) consist of a much thinner layer of cortical bone covering a network of cancellous (or spongy) bone, also known as trabecular bone (Laroche, 2002, Marieb & Hoehn, 2013, Paxton, 2012). According to Laroche (2002), blood enters the long bone through six groups of arteries. Because of this unique and highly vascular network, the bone marrow is constantly being perfused, and does not collapse in the presence of hypotension, hypovolaemia or shock (Hartholt *et al*., 2010, Levitan *et al*., 2009). Indeed, animal studies have shown that even in the presence of continuous blood loss, bone marrow perfusion and venous outflow are maintained at a time when peripheral vessels would be constricted (Paxton, 2012). A large sinus runs along the centre of the medullary cavity and acts as a reservoir for any substances collected within the IO space. Substances injected into the epiphysis will drain via medullary veins into this central medullary sinus. The sinus drains into further veins that run parallel to the groups of arteries (Laroche, 2002, Paxton, 2012). The sternum is defined as a flat bone (Marieb & Hoehn, 2013) and does not possess the typical characteristics of a long bone. Paxton (2012) suggests, however, that two types of bone can be used for IO infusion; bone that contains yellow marrow (typically the long bones) and bone that contains red marrow. The sternum contains a high level of red marrow (Marieb & Hoehn, 2013, Paxton, 2012).

Table 3.0 Summary of selected research papers

Study	Aim, sample and setting	Research design and methods	Major findings
Brenner *et al.*, 2008	Comparison of manual Man-IO and semi-automatic (EZ-IO) IO devices. 84 participants from specialist seminar attendance. Germany.	Prospective study Experimental design Randomised, non-blinded. 2 practice groups – evaluated and compared the 2 insertion approaches on cadavers.	The EZ-IO is more user friendly and is associated with fewer technical problems.
Gazin *et al.*, 2011	To assess the safety and efficacy of EZ-IO for difficult vascular access. 39 patients (34 adults and 5 children). Pre-hospital. France.	Prospective observational study.	EZ-IO is safe and has a high success rate of use in the out of hospital setting – suggests that it could be the preferred vascular access option whenever IV or fluid resuscitation is needed in an emergency.
Hartholt *et al.*, 2010	To determine which IO needle (Jamshidi, BIG and FAST1) is preferable for gaining access (n=92, 69=Adult). Helicopter medical team. Netherlands.	Single centre, single blinded prospective randomised trial	IV access remains gold standard and should not be replaced. IO is good alternative. The Jamshidi was placed significantly faster than the FAST. No difference in success or complication rate or user friendliness.
Hoskins *et al.*, 2012	To compare the pharmacokinetics of IO tibia and sternum drug delivery with central venous during CPR. US and Brazil.	Prospective animal study (pigs) Anaesthetised Pigs (n=13).Cardiac arrest induced by Potassium Chloride injection	Given the limitations of the animal model, the results are valid and useful. Recommended that sternal IO route be considered as the first choice of drug delivery during CPR when IV access has not been established, and that the tibial IO route is also justified as second choice.
Lamhaut *et al.*, 2010	To compare IO and IV access with and without protective equipment. Nine RN and 16 physicians. France.	Participants each given four simulated experiments and timed for successful access. Four experiments PVC & IO with and without protective equipment.	IO significantly quicker to timing of access in both situations - Mean time saved 20-24s under normal and 39-20s with CBRN.
Leidel *et al.*, 2010	To compare two IO access	Prospective randomised	EZ-IO faster and more

	devices, 40 patients. Consecutive admissions over an 18 month period that met the inclusion criteria. Germany.	study	successful than BIG but not statistically significant.
Leidel *et al.*, 2012	Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. Germany.	Prospective observational study success rates on first attempt of CVC and IO (n=40)	IO cannulation was significantly more successful and faster to gain when compared to landmark-based CVC IO access is not a surrogate for CVC and cannot replace it.
Levitan *et al.*, 2009	To determine skill acquisition and performance by using a battery-operated, intraosseous needle driver in cadavers. USA.	Prospective study (n=99)	EZ-IO requires minimal training, is fast and easy to use.
Molin *et al.*, 2010	To explore current use of intraosseous infusion in national emergency departments excluding trauma centres (n=19). Denmark.	On line survey sent to Head of Emergency Department.	General lack of consensus on indications, use and contraindications. Suggests need for training in the use of IO access.
Ong *et al.*, 2009a	To compare tibial and humeral IO access using the EZ-IO in a single centre (Emergency Department) (n=24 patients). Singapore.	A non-randomised prospective observational study.	All insertions were reported to be successful on first attempt except one – successful on second attempt. All insertions achieved within 20 seconds. Significantly increased flow rates with pressure bag than without one. No reported complications.
Ong *et al.*, 2009b	To determine the Ease of Vascular Access in Adults Using a Novel Intraosseous Access Device. Singapore.	Observational, prospective study using a simulation bone model.	EZ-IO appeared easy to use with high success rates of insertion with inexperienced participants.
Philbeck *et al.*, 2010	To compare pain and effectiveness of Lidocaine on IO access in different sites. USA.	Experimental study (n=16).	Conscious patients requiring IO infusion experienced less pain in the proximal humerus site.
Reades *et al.*, 2011a	To compare 1st attempt success between tibial and	Observational analysis.	Tibial IO needle placement appeared to be a more

	humeral IO insertion during out of hospital cardiac arrest. USA.	88 patients in out of hospital setting EMS.	effective insertion site than the proximal humerus.
Reades *et al.*, 2011b	To compare IO v Vascular Access during out-of hospital cardiac arrest. USA.	Randomised controlled trial. 182 patients enrolled – non traumatic out-of-hospital cardiac arrest.	Tibial IO was found to have highest first attempt success and quickest time for vascular access compared with IV and humeral IO access.
Reiter *et al.*, 2013	To compare potential for improved resuscitation using LMA and IO lines to standard ETT and CVC. USA.	Simulation trial involving 44 residents.	Using the LMA and IO device led to significantly faster establishment of an airway and vascular access in simulated cardiac arrest.
Santos *et al.*, 2013	To explore EZ-IO device implementation in a pre-hospital emergency service. Switzerland.	A prospective study and review of the literature.	74% cardiac arrest 26% non-cardiac arrest. EZ-IO effective in achieving vascular access in pre-hospital settings.
Schalk *et al.*, 2011	To explore the efficacy of the EZ-IO needle driver for out of hospital IO access. Germany.	A preliminary observational multi-centre study (n=77).	Of 22 responsive patients 18 reported pain on infusion regardless of Lignocaine. IO efficient alternative for vascular access and should be considered earlier.
Sunde *et al.*, 2010	To investigate emergency IO access in a helicopter medical emergency service. Norway.	A retrospective study analysing case notes in pre-hospital setting (n=78).	All emergency services should be familiar with the technique. EZ-IO faster and more reliable.
Wampler *et al.*, 2012	To investigate paramedics performance inserting humeral IO access in adults. USA.	A retrospective cohort analysis out of hospital setting.	Humeral IO access is a reliable method for obtaining vascular access.

Table 4.0 Summary and recommendations for best practice

- The intraosseous route is a viable alternative to prevent delayed initial vascular access.
- All clinical studies reviewed are limited to the ED or pre-hospital settings therefore further research is required to investigate the whole hospital approach.
- All IO devices are associated with minimal reported complications
- Pain is the significant issue for conscious patients on administration of fluids/flush; therefore Lidocaine is an absolute necessity following insertion.
- The EZ-IO® is the most popular and consistently used device in the adult population.
- Although the proximal humerus is the suggested first choice site, tibial access occurred more frequently and is considered easier and faster by practitioners.
- Initial competence is demonstrated with minimal preparation however ongoing competence and immediate response in the clinical emergency requires further exploration.
- Cost is a significant issue and may influence the choice of route and device therefore analysis of quality and cost effectiveness is required.