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# Use of Intraosseous Needles in Neonates: A Systematic Review

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**Abstract**
***Background:*** The use of intraosseous (IO) access during resuscitation is widely accepted and promoted in paediatric medicine but features less prominently in neonatal training. Whilst umbilical venous catheterization (UVC) is a reliable method of delivering emergency drugs and fluids, it is not always achievable in a timely manner. IO access warrants exploration as an alternative. ***Aim:*** Conduct a systematic review of existing literature to examine the evidence for efficacy and safety of IO devices in neonatal patients, from birth to discharge. ***Method:*** A search of PubMed, Ovid, Medline, and Embase was carried out. Abstracts were screened for relevance to focus on neonatal-specific literature and studies which carried out separate analyses for neonates (infants <28 days of age or resident on a neonatal unit). ***Results:*** One case series and 12 case reports describe IO device insertion into 41 neonates, delivering a variety of drugs, including adrenaline (epinephrine) and volume resuscitation. Complications range from none to severe. Cadaveric studies show that despite a small margin for error, IO devices can be correctly sited in neonates. Simulation studies suggest that IO devices may be faster and easier to site than UVC, even in experienced hands. ***Conclusion:*** IO access should be available on neonatal units and considered for early use in neonates where other access routes have failed. Appropriate training should be available to staff in addition to existing life support and UVC training. Further studies are required to assess the optimal device, position, and whether medication can be delivered IO as effectively as by UVC. If IO devices provide a faster method of delivering adrenaline effectively than UVC, this may lead to changes in neonatal resuscitation practice.


## Introduction

Intraosseous (IO) access was first used in 1922 [1] following the discovery of the highly vascular nature of mammalian long bones. In adults, IO access became widely used in the 1930–40s after a study by Tocantins and O'Neill [2] showed that substances injected via IO route were rapidly available in the systemic circulation



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with a high rate of successful insertion and minimal side effects. The IO route later fell out of fashion until the late 1980s, when it made a resurgence for use during resuscitation when other forms of access were not readily available and new devices were developed to make the IO route more accessible.

For adults and children, IO is now widely accepted and recommended by the International Liaison Committee on Resuscitation (ILCOR) [3, 4], UK resuscitation council [5], and the American Heart Association (AHA) [6] as a first-line method of central access in cardiac arrest and first or second line in a peri-arrest situation. Medical and nursing staff working in emergency departments (ED), resuscitation teams, paediatric wards, and pre-hospital care all receive regular training on IO insertion. IO access routes have even been used for administration and maintenance of general anaesthesia in children where attempts at intravenous (IV) access have failed [7]. The recommendation for the use of IO access has been adopted worldwide by pre-hospital service providers [8, 9], ED, and in-hospital teams and directly recommended in parts of North America for pre-hospital neonatal emergencies [10]. Several devices are available for IO access, some are purpose-built for neonatal use, whilst others have been adapted from other purposes. Table 1 shows a summary of devices described in the literature for IO access on neonates and children.

However, whilst IO access training forms part of compulsory paediatric resuscitation courses in the UK (advanced paediatric life support [APLS], European Pediatric Advanced Life Support), it does not feature prominently in the neonatal equivalent, which focuses on umbilical venous access (UVC) alone. IO access is only described briefly as an alternative method of access in neonates in the UK Neonatal Life Support (NLS) course manual but is not taught as a care standard during the course. Consequently, some neonatal units do not have IO access devices available and rely on UVC or peripheral IV access in emergencies. However, once the vessels have closed and the cord stump has dried and shrivelled, UVC access becomes almost impossible.

This divide in clinical practice requires attention, as infants with a similar presentation may receive entirely different methods of central access based predominantly on where in a hospital they are treated (neonatal unit/postnatal ward versus ED). If an IO device can be sited effectively in an infant of <28 days in the ED, then it is likely to be similarly feasible in the NICU, should conventional routes of access fail. The potential role for IO access devices in neonates has been discussed previously. Fisher and Prosser [11] reported in 2000 that fluid boluses could be more rapidly infused in vitro by IO needle than by neonatal IV cannula, owing to its wider gauge. In 2006, Engle [12] recommended that IO devices were of most use in a pre-hospital setting and in hospitalised infants without established IV access, where clinicians' skills in IO access was greater than in IV access. DeBoer et al. [13] concluded in 2008 that despite the lack of evidence base, IO access could save lives where IV access was not possible. More recently, Schwindt [14] and Wyllie [15] debated whether the brief description of IO use during neonatal life support, as reported in the 2015 neonatal resuscitation guidelines [4], was a shortcoming or a reflection of the lack of supporting evidence for IO device use in neonates.

The principle of IO access is to insert a needle into the medullary cavity of a long bone, usually the proximal (at least 10 mm from the tibial tuberosity [16]) or distal tibia, distal femur [17], or head of humerus. Other sites include the sternum and flat portion of the pelvis, but these are less convenient during resuscitation. According to the device training, care must be taken in infants and young children to avoid the epiphyseal plates [7]. IO needle position may be confirmed by any of the following: aspiration of bone marrow, checking that the device is free-standing in the bone, or infusing a small volume of fluid under direct vision and monitoring for extravasation [18] (aspiration of bone marrow may not always be possible, even in a correctly placed IO device).

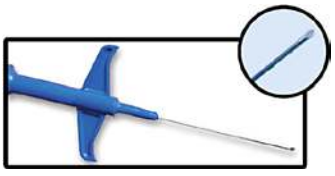
The long bone circulation then carries the infused medication or fluid into the central circulation. Drug administration IO has been shown to be comparable to the IV method. Current recommendations support the use of the same drug and fluid doses whether administered by IO or IV route [19]. However, at present the efficacy of drugs given via the IO route into the transitioning circulation of a newborn human has not been investigated.

Careful monitoring of an IO device is required throughout its use. Complication and failure rates appear higher in younger patients [20]. This is possibly due to the smaller medullary cavity diameter in this patient group.

*Aim*

To review the literature on IO device use in neonates (term or preterm infants under 28 days of age or inpatients on neonatal units, from birth to discharge) to determine whether there is evidence to suggest that IO devices can be sited safely, effectively, and quickly in the neonatal population and used to administer emergency medication.

**Table 1.** A summary of IO devices described in the literature (images from manufacturers' websites)

| Image | Manufacturer | Device type | Purpose-built for IO? | Licenced weight or age use | Needle descriptions |
|---|---|---|---|---|---|
|  Arrow®EZ-IO® | Teleflex, USA | Battery-powered driver | Yes | >3 kg | 15 G<br>15, 25, 45 mm needles |
|  Cook Needle | Cook Medical, USA | Hand driven | Yes | <24 months for smallest needle | 14, 16, or 18 G<br>25, 30, or 40 mm needle |
|  Bone injection gun (BIG)* | PerSys Medical, USA | Spring loaded | Yes | 0–12 years (with adjustable depth) | 18 G (paediatric) |
|  New intraosseous device (NIO) paediatric* | PerSys Medical, USA | Spring loaded | Yes | 3–12 years (with adjustable depth) | |
|  Butterfly needle | Multiple | Hand driven | No | Not licensed for IO | 19–25 G<br>19 mm |
|  Mallarme needle | Laurane Medical, France | Hand driven | Bone marrow biopsy needle | | 16 G<br>20, 30, or 50 mm |
|  Spinal needle | Multiple | Hand driven | No | Not licenced for IO | Paediatric needles<br>22–25 G<br>50 mm<br>(may not connect to standard syringes) |

Color version available online

**Table 1** (continued)

| Image | Manufacturer | Device type | Purpose-built for IO? | Licenced weight or age use | Needle descriptions |
|---|---|---|---|---|---|
|  Jamshidi needle | BD, USA | Hand driven | Bone marrow biopsy needle, "indicated for paediatric IO infusion" | "Paediatric" | 15–18 G<br>48–79 mm<br>(with adjustable depth guard) |

FAST1 not included as it is a sternal device. * Not used on neonates.

## Methods

Database (PubMed, Ovid, Medline, Embase) searches were performed using the MeSH terms "neonate" OR "infant" AND subject term "intraosseous." 360 publications were returned from the PubMed search, and 512 from the Ovid search. Titles were then screened for relevance and duplications. Articles were screened to focus on neonatal-specific literature including case series, reports, or trials that included neonates or neonatal models (term or preterm). Studies including populations of mixed age groups were excluded unless they made specific mention of, or provided separate analyses for, infants under 28 days of age or those resident within the neonatal unit. Abstracts for which the full text was unavailable or in a language other than English, German, Spanish, Italian, or French were excluded. In one case, the author was contacted and kindly sent a full-text copy of the paper. Literature which addressed the research question ($n$ = 19) was assessed independently, initially by F.E.E. and C.C.R., then by A.S. The corresponding PRISMA flow diagram and checklist are available as online supplementary materials (see www.karger.com/doi/10.1159/000502212).

## Results

There have been no clinical randomised controlled trials comparing IO access in neonates with other forms of access. Thus, this literature review was limited largely to observational and simulation studies. There have been several case series including children under 1 year of age, but only one [21] looking specifically at neonatal patients.

*Case Series*

The largest case series of neonatal IO use [21] detailed the insertion of 30 IO needles in 27 neonates (weight range 515–4,050 g, mean 1,780 g) with a mean gestational age of 31.5 weeks (range 25–41 weeks). All 30 infants had IO access established in the proximal tibial region by Cook needle (Cook Medical, Bloomington, IN, USA). All infants survived initial resuscitation and a variety of drugs were given via IO (volume expanders, catecholamines, sodium bicarbonate, analgesics, glucose, blood products, antibiotics). The IO needles were left in place for 30 min to 20 h. The reported complication rate was 13% (4/30; dislocation, subcutaneous necrosis, haematoma) and the authors concluded that IO was a suitable alternative form of central access should other routes (UVC, peripheral cannulation) fail. However, similar results have not been reproduced since their original publication in 1999.

As part of a larger case series ($n$ = 152), Glaeser et al. [22] reported 23 instances where proximal tibial IO access was used in neonates. Although the rate of successful insertion was 78% in children 0–1 years of age, no separate analyses were performed on the neonatal data.

*Human Case Reports: Neonates Only*

There are few case reports of IO use on neonatal units (14 cases included in Table 2, 16 insertions). In these cases, IO was used to good effect once other access possibilities had failed. Lake and Emmerson [28] reported that an IO line (butterfly needle in the proximal tibia) was used effectively for 6 days, which is well beyond the recommended length of use by IO manufacturers, Teleflex® (USA). Suominen et al. [23] report a rare but significant side effect of limb ischaemia leading to amputation, and although the infant made a good recovery, significant overlying skin necrosis was noted by Carreras-González et al. [26]. A severe complication rate of 5/16, 31% was observed.

**Table 2.** A summary of neonatal case reports on intraosseous needle use

| Author | Gestational age of infant, weeks | Weight of infant, g | Age at IO insertion | Site of insertion, type of device (if stated) | Indication for IO insertion | Medication infused through IO | Length of time left in situ | Complications |
|---|---|---|---|---|---|---|---|---|
| Suominen et al. [23], 2015 | | | 24 days | Proximal tibia, distal femur, contralateral tibia, EZ-IO | Circulatory collapse, VT | Fluid, adrenaline, noradrenaline | >24 h | Dislodged twice, ischaemic lower limb leading to below-knee amputation |
| Oesterlie et al. [24], 2014 | | | Newborn | Proximal tibia | | Antibiotics, fluids, calcium | | Extravasation: trans-tibial amputation after 1.5 months |
| Heyder-Musolf et al. [25], 2011 | "Preterm" | 1,300 | 15 days | Tibia | Sepsis, perioperative | Fluids | | |
| Carreras-González et al. [26], 2012 | | | 22 days | Tibial plateau | Cardiac arrest | Adrenaline, bicarbonate, crystalloid | | Erythema, swelling, cutaneous necrosis |
| Singh Tomar and Gupta [27], 2006 | Term | | Newborn | Tibia | Haemorrhagic shock | Fluid, dextrose, antibiotics | 2 h | None |
| Singh Tomar, and Gupta [27], 2006 | 34 weeks | 1,700 | 12 days | | Sepsis | Fluids, drugs | 5 h | None |
| Lake and Emmerson [28], 2003 | 25 | | | Proximal tibia, butterfly needle | Acute deterioration | Fluids, antibiotics, antihypotensives | 6 days | None |
| Nasimi et al. [29], 1998 | 34 | | 8 days | Proximal tibia, Cook needle | Klebsiella sepsis, septic shock | Fluid, adrenaline, blood product, antibiotics, albumin, dopamine, dobutamine | 14 h | None |
| Ramet et al. [30], 1998 | 28 | 800 | 38 days | Tibial plateau, Cook needle | Acute deterioration, respiratory failure | Albumin, adrenaline, atropine, sodium bicarbonate, antibiotics, dextrose, dobutamine | 24 h | None |
| Katz and Wojtowycz [31], 1994 | | | 2 weeks | Proximal tibia | Collapse following surgery | | | Tibial fracture |
| Martino Alba et al. [32], 1994 | | | 10 days | Distal tibia (bilateral, 2 lines placed), "intraosseous needle" | Aortic coarctation, shock, acidosis | Fluids, adrenaline, dopamine, sodium bicarbonate, human albumin solution, fresh frozen plasma, antibiotics, vitamin K, pancuronium | 8 h | None |
| Kelsall [33], 1993 | 27 | 1,920 | 144 days | Tibial plate, spinal needle | Wound dehiscence, collapse | Albumin | <12 h | None |
| Kelsall, [33], 1993 | 34 | 4,600 | 41 days | Tibial plate, spinal needle | Hypoglycaemia, shock | Albumin, 10% dextrose | <12 h | None |
| Ghirga et al. [34], 1992 | Term | 3,500 | 15 days | Left tibia, bone marrow needle | Pneumonia, shock, cardiorespiratory collapse | Adrenaline, sodium bicarbonate, fluid | 40 min | No direct complications; further deterioration and death after 40 min |

*Human Cadaveric Studies*

Most neonatal case studies report use of IO device in the proximal tibial region. Mogale et al. [35] performed a study on 30 neonatal cadavers weighing over 1.5 kg using a 22-gauge spinal needle inserted into the humerus, in order to determine whether the head of humerus (used in adults and older children) is feasible in neonates. Using a head of humerus site may provide more rapid circulation to the heart than the tibial site. They concluded that the humeral site was likely to be safe as the needles were inserted (using external landmarks only) an average of 11 mm from vital neurovascular structures.

A 2018 study on 15 term and preterm stillborn infants [36] compared semiautomatic battery-driven drill-inserted IO needles (EZ-IO, Teleflex, USA) with manually inserted IO needles (butterfly needle or EZ-IO needle) into the proximal tibial position. The position accuracy was assessed using CT spectroscopy and judged to be successful by instilling contrast medium into the bone marrow cavity. They reported a median medullary diameter of 4.0 mm (IQR 3.3–4.7) and success rates of 61.1% (95% CI 39.7–78.9%) for manual butterfly needle insertion, 43.0% (95% CI 23.4–65.0%) for manual insertion of EZ-IO, and 39.7% (95% CI 24.1–57.7%) for drill-inserted EZ-IO needles. The OR of success is quoted as 2.4 (95% CI 0.8–7.6) when comparing butterfly needles with drill-inserted needles. Despite the lack of statistically significant data, they concluded that manual butterfly needle insertion would be preferable to semiautomatic drill use in term and preterm infants.

*Simulation*

IO use in adults is proven to be a successful intervention in relatively inexperienced hands [37]. The infrequent nature of the need for IO insertion in any population means regular training and updates are necessary. Simulation is an effective method of providing IO access training within a clinical context. Lo and Reynolds [38] reported that senior practitioners who have used IO devices in the past make the decision more readily to use them again than junior clinicians with no experience with IO devices, suggesting clinician confidence in the technique, once the clinician is experienced in IO device use.

Three studies have compared the use of IO and UVC access in neonatal simulation. Abe et al. [39] compared the speed and ease with which medical students could insert IO (turkey bone or plastic infant leg) and UVC (simulated cord) access before and after training. Attempts were timed and rated for difficulty according to a validated visual analogue scale (VAS). Abe et al. [39] found that procedure difficulty scores were significantly lower ($p < 0.001$) in the IO groups for both the pre- and post-training attempts and the time taken for insertion was shorter in the IO group (initial attempt 52 vs. 154 s, $p < 0.001$; second attempt 45 vs. 95 s, $p = 0.11$). Rajani et al. [40] performed a similar study involving 40 healthcare providers who were shown instructional videos for both IO and UVC and allowed time to practice before a timed attempt. IO insertion was on average 46 s faster than UVC ($p < 0.001$).

A retrospective study by Schwindt et al. [41] analysed 59 simulated resuscitation scenarios in Germany and Austria between 2015 and 2017. After lecture-based training, experienced teams chose between IO and UVC access as a first line within simulated scenarios. Seventy-one percent (42 teams) chose IO access. Resuscitation teams working in more specialised perinatal units were more likely to choose UVC over IO than those working in lower-intensity units. The average time from decision to first flush was faster for IO than for UVC across all resuscitation teams (86 vs. 199 s, $p < 0.001$), suggesting that IO is faster, even if the operator inserting the UVC is experienced in UVC insertion. However, they were unable to assess the accuracy of positioning of either form of access due to the nature of the mannequin used.

## Discussion

*Safety and Efficacy*

Available literature was reviewed to assess the safety, efficacy, and speed of insertion of IO devices in the neonatal population. No randomised controlled clinical trials or meta-analyses were available. Details of 46 IO needle insertions in 41 neonates (some with multiple insertions) were detailed across a case series and 12 case reports. Two neonatal cadaveric studies assessed the success rates of neonatal IO placement. Three neonatal simulation-based studies assessed the speed and ease with which IO devices could be placed in neonatal mannequins.

Although not a widely publicised practice, IO access has been used successfully in neonates for some time, both in neonatal units worldwide and in emergency departments. Despite the apparent popularity of IO devices, there is a lack of data with which to establish accurate success and complication rates of neonatal IO placement. There are also insufficient data to ascertain the best device to use, where to place the device, how to insert the device or to guide how long IO devices may be safely left in place. There is no clinical study directly comparing their use during resuscitation with that of the UVC.

Although speed of decision to first infusion time is important, it has not been demonstrated whether IO is as effective as UVC in allowing drugs to reach the heart in the circulation of the newborn, during transition from fetal to adult circulation. Examples of successful outcomes with IO use are seen in the literature, but a letter in response to a case series on older children in 1999 [17] highlighted that not every hospital has had positive experiences of IO access. A recent study has reported that 3 of 6 IO devices placed (in older children) by paramedics were found to be misplaced and urged that staff be appropriately trained in IO device placement and monitoring. Studies have shown that relatively little training is required for inexperienced staff to use IO with high success rates and that staff who have used them once are willing to do so again [38, 39, 42].

A study [43] comparing administration of adrenaline by humeral IO and IV routes in adult pigs following cardiac arrest, found a significantly greater systemic adrenaline concentration at 30 s post administration in the IO group, and no significant differences in systemic adrenaline concentration at 60, 90, 120, or 240 s. Although this study was small and related to adult pigs ($n = 15$), it suggests that systemic availability of drugs administered via IO route is at least comparable to IV administration. Others have assessed adrenaline infusion in newborn lambs and shown similar bioavailability using IV and IO routes [44]. There is reported evidence of successful use of IO devices in human neonates beyond the immediate perinatal period, but only a few case reports of IO devices used successfully during resuscitation at birth, possibly owing to the availability of UVC access at birth.

The UVC route is only possible for a limited time after birth and may be complicated by malpositioning (often only detected later by X-ray or ultrasound) or extravasation [45]. Therefore, there is a need to establish the evidence base for an alternative both around the time of birth and for infants with circulatory collapse in neonatal and postnatal wards. A study by Barber and Wyckoff [46] showed that 77% of infants who did not respond to an initial dose of endotracheal adrenaline subsequently responded to intravenous adrenaline. A review by Wagner et al. [47] concluded that as the endotracheal route can only be used for a limited range of drugs (usually naloxone and adrenaline) that are given at much higher (×10) doses [48] and it cannot be used for fluid boluses or blood products, IO access should be considered when central or peripheral venous access fails. IO access is also useful for resuscitation of infants with circulatory collapse who are beyond the initial perinatal period, and for whom UVC is not a possibility.

The complications associated with IO devices include malpositioned needles, displaced needles, extravasation, infection (local infection or osteomyelitis), fracture, compartment syndrome, limb ischaemia, and more rarely fat or air emboli [49–51]. It is thought that early identification of extravasation may help to avert more severe complications such as limb ischaemia and compartment syndrome [18]. Complication rates amongst the infants in the case reports and case series (Ellemunter et al. [21] 13%, collected case reports [5/16 insertions, 31%]) are higher than those quoted in previous studies for older patients. Whilst this may be reflective of the more severe cases lending themselves to case reports, complication and failure rates of IO device placement are higher in younger patients [20]. Severe complications of IO device placement have been reported in neonates including fractures, limb ischaemia, and the need for amputation [23, 24, 31]. The risk of such complications may only be acceptable in life-threatening emergencies where there are no other forms of venous access available. Further training of neonatal teams in IO device use may reduce complication rates.

*Training and Implementation*

For a resuscitation team to work cohesively together, both medical and nursing staff should have appropriate training on all devices to be used during resuscitation. Regular role-appropriate training in IO device insertion and monitoring is imperative for both medical and nursing staff if these are to be recommended as a part of resuscitation. Many trainees on paediatric rotations are trained in IO device use as part of mandatory training updates (e.g., APLS), but staff who work exclusively on the neonatal unit (e.g., consultants, staff or trust grade doctors, nursing staff) may not receive this training. In a brief telephonic survey of UK neonatal units conducted by the authors, 75% (15/20) reported that they had IO devices available for use as part of their resuscitation equipment, but none reported that these were regularly used.

Cadaveric studies have highlighted the small margin for error when attempting to insert an IO device into the 4-mm-wide medullary cavity of a neonate [36]. With the added pressure of a resuscitation scenario, the failure rate and time taken in vivo may be higher than in simulated studies. However, the reported success rates from relatively inexperienced users in IO devices appears promising [37]. A German study including adult and paediatric patients reported a first-time use success rate of 85% [37]. The relatively rare need for emergency access in a neonate (<1% deliveries) means that many members of the team

attending a neonatal emergency may be relatively inexperienced in performing emergency UVC or IO access.

During resuscitation at birth, once ongoing aeration of the lungs is established and chest compressions are initiated, adrenaline and other resuscitation drugs should be given rapidly to increase myocardial blood flow [52] and ensure the best possible chance of a return of spontaneous circulation. Simulation studies suggest that IO may be easier and faster than UVC for inexperienced users. Practical considerations of attempting to site a UVC versus attempting to site an IO device during cardiopulmonary resuscitation may favour IO access as there is often a short interruption to chest compressions whilst the practitioner compressing the chest changes position to allow access to the umbilicus. If the simulation study findings that IO access is significantly faster than UVC access translate into clinical practice, IO may even prove a preferable alternative to UVC in some cases. This may allow for more rapid delivery of adrenaline during cardiopulmonary resuscitation, potentially leading to improved clinical outcomes.

The proximal tibial site is used most frequently in the studies reviewed, but Mogale et al. [35] suggest that the humerus may be a safe alternative site for IO access in neonates. They did not, however, quote a success rate in the needles reaching the medullary cavity of the bone. Adult models have suggested that battery-driven insertion devices increase success rate beyond those of hand-driven or spring-loaded devices [53–56]. However, this has not been reflected in the single available study in the neonatal population (Fuchs et al. [36]), and it has been suggested that a screwed butterfly needle may allow for better control of position of the IO needles than semiautomatic devices where there is a small margin for error [35]. Further studies are needed to determine which type of needle and which method of insertion is optimal in the neonatal population.

### Limitations

There is very little neonatal-specific literature on IO access. As a result, due to a lack of randomised clinical studies, this review has been limited to case series, case reports, and cadaveric and simulation studies. Case series and reports often focus on specific benefits of treatment and complications and thus may highlight exceptions rather than routine cases, which therefore have limited generalisability. A further limitation was the timescale over which the included studies were performed. New devices have become available and existing devices refined over the past 27 years since 1992, when the first included case report was published.

It was not possible to find full-text versions of all potentially relevant case reviews, as some were unavailable or written in languages other than English, Italian, Spanish, German, or French.

### Conclusion

IO device use is currently taught in APLS courses in the USA, Australia [57], and Europe but not given significant weight in their neonatal counterparts. Whilst there is no evidence to suggest that IO access is preferable to UVC, it represents an effective alternative when all methods of UVC and IV access have failed or are not possible in a resuscitation scenario, either in the delivery suite or on the neonatal unit. IO is likely to be more helpful in the latter where the umbilical cord has dried.

Safe and successful use of IO devices requires training in their insertion and monitoring. At present, not all neonatal medical and nursing staff have regular IO device training, nor are IO needles available in every neonatal unit. Staff on the neonatal unit should have access to IO devices as an alternative for when other methods of IV access have failed and they should be taught how to insert IO needles, assess for correct positioning and monitor for complications. However, training in IO device use should be in addition to, and not detracting from, training on proven resuscitation techniques such as airway manoeuvres, respiratory support, chest compressions, and UVC access.

Careful consideration should be given to the rate of complications associated with IO access in neonates when evaluating the risks and benefits of IO device use; whilst it may not be appropriate to use an IO device on a relatively stable baby, timely insertion of an IO device may provide a lifesaving alternative where other routes have failed.

Additional studies are required to establish the effectiveness and pharmacokinetics of drugs given IO in the transitional circulation of a newborn. Further investigation into the success and complication rates of IO device use in neonates may help to establish factors affecting success of device placement including needle type, method of insertion, and location of insertion. If IO devices can be refined to deliver adrenaline faster than UVC, this may lead to a change in practice in neonatal resuscitation, provided IO administration is of equal efficacy to that via UVC.

## Statement of Ethics

The authors have no ethical conflicts to disclose.

## Disclosure Statement

None of the authors has a conflict of interest to declare.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## Author Contributions

C.C.R. and F.E.E. conceived the concept of the review. A.S. wrote the draft manuscript. P.R.R., C.T.R., G.R.P., S.B.H., and C.C.R. contributed to the completion of the manuscript.

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