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Saving the critically injured trauma patient: a retrospective analysis of 1000 uses of intraosseous access

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ABSTRACT

Objective Intraosseous access (IO) is becoming increasingly accepted in adult populations as an alternative to peripheral vascular access; however, there is still insufficient evidence in large patient groups supporting its use.

Methods Retrospective review. This paper reports on the use of IO devices over a 7-year period from August 2006 to August 2013 during combat operations in Afghanistan. A database search of the Joint Theatre Trauma Registry (JTTR) was carried out looking for all the incidences of IO access use during this time. Excel (Microsoft) was used to manage the dataset and perform descriptive statistics on the patient demographics, injuries, treatments and complications that were retrieved.

Results 1014 IO devices were used in 830 adult patients with no major complications. The rate of minor complications, the majority of which were device failure, was 1.38%. 5124 separate infusions of blood products or fluids occurred via IO access, with 36% being of packed red cells. On average, each casualty received 6.95 different infusions of blood products and fluids, and 3.28 separate infusions of drugs through IO access. 32 different drugs were infused to 367 patients via IO, the most frequent being anaesthetic agents. IO access was used in the prehospital environment, during tactical helicopter evacuation and within hospitals.

Conclusions IO access can be used to administer a wide variety of life-saving medications quickly, easily and with low-complication rates. This highlights its valuable role as an alternative method of obtaining vascular access, vital when resuscitating the critically injured trauma patient.

Key messages

What is already known on this subject
Intraosseous (IO) access is widely accepted as an alternative method of obtaining vascular access in critically ill paediatric patients. It is becoming more common in adult practice, but there is little published evidence supporting its use.

What this study adds
This retrospective review of 830 adult trauma victims in Afghanistan found that IO access could be successfully used to infuse a variety of drugs, fluids and blood products in a range of settings. Among 1014 insertions, there were no major complications and the minor complication rate was 1.38%.

INTRODUCTION

Rapid circulatory access is a prerequisite for fluid resuscitation as well as for the administration of critical care drugs in trauma and periarrest patients. Peripheral cannulation is often challenging in the shocked and peripherally shutdown patient, and the degree of urgency is often directly proportional to the difficulty of insertion. Traditionally the alternatives to peripheral venous cannulation have been central venous access and venous cut down, both of which are time-consuming procedures, require specific skills and have significant failure rates as well as complications. Central venous cannulation (CVC) has been shown to have complication rates between 14% and 15% and insertion times of approximately 2–3 min.[1] Venous cut down, the use of which has declined following the introduction of the Seldinger technique, has been shown to take an average time of 5.6 min to complete, with lower flow rates than that of CVC and complications occurring in 2–15% of insertions, which include haemorrhage, damage to the femoral artery and nerve, thrombophebilits, wound breakdown, infection and embolism.[1]

The use of intraosseous (IO) access has been accepted for many years in paediatric practice, with substantial evidence supporting its use as a safe and rapid alternative to peripheral venous access.[2] It is becoming accepted for use in the adult population as well and is supported by international guidelines.[3 4] IO access can be achieved faster than peripheral intravenous cannulation or saphenous venous cut down,[5 6] and personnel can be trained easily and remain proficient in its use. In addition, the IO route has been shown to be similar to the intravenous route in terms of pharmacodynamics and pharmacokinetics.[7] The three most popular devices on the market are the Bone Insertion Gun (BIG) (WaisMed, Israel), which fires a spring-loaded needle into the bone; the First Access in Shock and Trauma (FAST1) (Pyng Medical Corporation, Richmond, Canada), which again uses a spring to fire a trochar into the sternum; and the newer EZ-IO (Vidacare, San Antonio, USA), which uses a battery-powered driver, similar to a hand-held drill, to place a specially designed needle into bone. The EZ-IO and FAST1 devices were introduced by the UK Defence Medical Services in late 2006 for use on combat operations.[8]

Much of the current literature on IO access only reviews small numbers of patients, and very few papers focus on transfusion of blood products or

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complication rates.[1 9–11] We conducted a retrospective study of the use of IO access in 830 patients over a 7-year period, between August 2006 and August 2013, during Operation Herrick in Afghanistan.

METHOD

The Joint Theatre Trauma Registry (JTTR-UK) is a database of all trauma patients, military and civilian, treated by the Defence Medical Services in Iraq and Afghanistan, and it contains details of the mechanism of injury and management of each patient. Data are collected prospectively by Trauma Nurse Coordinators (TNC) who are present when the patient arrives in hospital. The TNC often record data directly themselves, collect all of the pre-hospital information and copy the hospital notes in order that the JTTR data are both comprehensive and accurate. Where possible the patient will be interviewed to complete entries and to correct any contradictions in the notes. Follow-up of the patient and data entry continues throughout the patient journey and will continue for the weeks and months that the patient continues to undergo treatment. Complications of treatments can be recorded at any stage. Access to the registry is necessarily restricted as it contains both confidential medical details and military operationally sensitive information. Permission to access the database was granted on 6 November 2013 by the Academic Department of Military Emergency Medicine. No patient confidential details were sourced from the registry. A database search was carried out looking for all instances of IO access use in adults between August 2006 and August 2013. Adults were defined as patients aged 17 or above. Patient demographics, injuries, treatments and complications were retrieved. Excel (Microsoft) was used to manage the dataset and to perform descriptive statistics on the results obtained.

RESULTS

Between August 2006 and August 2013 (60 months), a total of 1014 IO devices were inserted into 830 adult patients; 67.6% of whom were military (n=562; 292 UK forces, 270 coalition forces) and 31.6% (n=262) were civilian. The average age of the patient was 26.4 years, ranging from 17 to 77 years. The devices were used at various different echelons of care from the frontline (25.6% n=260), during helicopter evacuation (63% n=639) and back at the Role 3 Hospital at Camp Bastion (11.6% n=118). The mean injury severity score (ISS) for these patients was 32.42 (range 1–75) of which 129 were classed as unsurvivable (ISS 75). Survival to discharge was 67.6% (n=562). The most common mechanism of injury was explosion (improvised explosive device, mine, mortar, rocket propelled grenade) at 66.7% (n=555), followed by gunshot wound at 29.9% (n=249). Just over two-thirds of patients sustained a blast-induced traumatic amputation (64.8% n=538). For these 538 patients, the use of IO access will have been the first choice method of obtaining access, complying with in-theatre military protocols. For the remaining casualties, it is not known whether IO access was used primarily or as a rescue technique following failure of peripheral cannulation.

There were a total of 1205 separate infusions of drugs, received by 367 patients (table 1). Thirty-two different medications were infused via the IO devices, the most frequent being anaesthetic induction agents (61.8% n=745) and analgesia (14% n=164). These medications were given in various environments, from Role 1 (close to the frontline), during evacuation via the helicopter-borne medical emergency response team (MERT), and in the Role 3 Hospital at Camp Bastion. On average, each patient received 3.28 different drugs via IO access.

Table 1 Summary of the use of IO access during Operation Herrick

	Number	Range/percentage
Demographics		
Age	26.4	17–77
Military	562	67.60%
UK Forces	292	
Coalition	270	
Civilian	262	31.60%
Injuries		
Mechanism		
Explosion	555	66.70%
GSW	249	29.90%
Other (RTA, burns, stabbing)	26	3.13%
Traumatic amputations	538	64.80%
Injury severity score	32.42	1–75
Outcome		
Survival	562	67.60%
Fatalities	268	32.30%
Location of IO insertion		
R1	26	25.60%
Helicopter evacuation	639	63.00%
R3	118	11.60%
Infusions		
Drugs—total number	1205	
Anaesthetic induction agents	745	61.80%
Analgesia	169	14.00%
Tranexamic acid	82	1.60%
Blood products and fluids—total number	5124	
Packed red cells	1881	36.90%
FFP	1497	29.34%
Platelets	619	12.08%
Cryoprecipitate	410	8.00%
Crystalloid	560	10.93%
Colloid	108	2.11%
Hypertonic saline	49	0.96%
Complications		
None	816	98.62%
Major	0	0.00%
Minor	14	1.38%
Placement failure	8	
Failure to infuse	1	
Fractured needle	5	

IO, intraosseous; R1, frontline; R3, Camp Bastion Hospital.
RTA; road traffic accident.

Eighty-two patients received tranexamic acid (TXA) via IO access, the majority during helicopter evacuation (n=78). The survival rate of patients receiving TXA was 69.2% (n=54). There were no complications recorded from administering TXA via an IO device.

There were 5124 separate infusions of fluids and blood products given to 737 patients, with the most frequent product used being packed red blood cells; 36.8% (n=1881) followed by fresh frozen plasma (FFP); 29.3% (n=1497). On average, each patient had 6.95 different infusions through an IO device. Packed red cells were successfully transfused 1881 times over the 7-year period of this study; haemolysis was not noted either clinically or in the laboratory. Again these products were given in the three different environments.

Hypertonic saline was administered via IO access 49 times during the reporting period with no complications reported.

There were no serious complications noted, and 14 minor complications (1.38%) that centred on device failure; placement failure (n=8) or failure to infuse through the device itself (n=1). In addition, the FAST needle has been found to fracture (n=5), leading to a small retained foreign body within the sternum, in one case resulting in a small localised infection, and another requiring removal by general anaesthetic.[12]

DISCUSSION

This paper demonstrates the safe and effective use of IO access in a large number of adult trauma patients in a variety of situations; from the frontline, to tactical helicopter evacuation and in hospital.

Despite military experience of successful blood infusions via IO access, there is little previous published work concerning the reliability of infusion of blood and drugs via the IO route and much of it is based on swine models[13] or case reports.[14] Watson *et al*[15] compared two different IO devices (FAST vs EZ-IO) in 187 patients and demonstrated that drugs, blood products and fluids can all be delivered with acceptable flow rates via the IO route when administered under pressure. Our findings support this evidence, demonstrating that a wide variety of drugs, fluids and blood products can be infused through IO access successfully.

A recently published paper[16] however contests this, stating that "nothing of substance can be achieved by transfusing blood via the IO route in damage control resuscitation". Harris *et al*[16] analysed flow dynamics using a theoretical model of porous media and demonstrated that flow rates through IO access can be markedly limited by the viscosity of the blood products and the permeability of cancellous bone in the IO space. The permeability of bone is significantly higher in younger patients, and the assumption they extrapolated from this was that attempting to infuse blood products via IO access would create more of an obstacle in the military population. They stated that the pressure needed to attain flow rates adequate for resuscitation exceeds the pressure levels tolerated by the infusion system and would risk causing haemolysis. Their recommendation therefore was to avoid the IO route entirely when blood transfusion is required. The data collected via the JTTR database strongly dispute this recommendation, with the experience of 88.7% of casualties having had an infusion of one or more of the following; crystalloid, colloid, packed red cells, FFP, platelets or cryoprecipitate without evidence of haemolysis. Although the time the infusion is started is recorded in the notes, overall time to administer blood products is not part of the data set. However, many prehospital transfer times in this environment are in the order of 10 min and during this period the prehospital care team are able to transfuse two units of packed red cells and two units of fresh frozen plasma via humeral head IO needles by using a 50 mL syringe, a three-way tap and a warming device. This implies it can take 5 min or less to administer a unit of blood product through a humeral head IO needle. Real-life experience would suggest that removing IO access from the armamentarium of the trauma practitioner on the basis of theoretically calculated flow rates would be a mistake.

The Military Application of Tranexamic Acid in Trauma Emergency Resuscitation (MATTERs) study[17] demonstrated that the use of TXA in conjunction with a blood component-based resuscitation following combat injury results in improved measures of coagulopathy and survival. TXA was administered without complications. There is some evidence in swine models that the use of hypertonic saline can cause harm to the bone marrow;[18] however, our data suggest that this caution is potentially misplaced.

COMPLICATIONS OF IO ACCESS

Of the papers available on the uses of adult IO access, few make any attempt to look at complications. In paediatric patient groups, serious complications are rare with rates of less than 1% for osteomyelitis, compartment syndrome and bone fractures.[19 20] In a literature review of 30 studies of IO infusion, with a total number of 4270 paediatric patients, Rossetti *et al*[2] reported the rate of osteomyelitis to be 0.6%. Extravasation leading to compartment syndrome has been reported 16 times in children, and in 5 cases subsequently led to amputation.[9] Handheld IO trochars are thought to be more likely to result in extravasation around the needle than mechanical devices such as the EZ-IO. Damage to the growth plate is a common concern in paediatrics, but no study to date has demonstrated any long-term effects on growth following the use of IO devices.[9] Other rare reported serious complications have included skin necrosis and popliteal artery thrombosis.[9] Reviewing literature concerning adult populations, to date only two case reports demonstrate serious complications. In the first report, Henson *et al*[21] published a case report of tibial subacute osteomyelitis with IO abscess in a 62-year-old man 6 months after an insertion of an IO needle. The patient did suffer from multiple comorbidities, including type 2 diabetes, and was colonised with multi-resistant staphylococcus aureus (MRSA) which may have predisposed him to this complication. d'Heurle *et al*[22] described a case of compartment syndrome following IO infusion in a patient with an unrecognised tibial fracture, which is the first documentation of this complication in adults. Our findings of no major complications following 1014 insertions of IO devices support the current literature suggesting that serious complications from the use of IO access in adults are rare.

Minor complications

Minor complications largely consist of failure of the procedure. Excluding case reports, successful first attempt insertion rates range from 90% to 96%.[6 10–11 23 24] These papers describe reasons for failure to include inability to infuse, broken needles, incorrect placement (one was inserted into the tibial plateau) and extravasation. Our findings support the previously published research, both in terms of low-complication rate (1.38%) and the reasons for failure. The finding in our data of a retained IO needle in a patient's manubrium sternum has been previously published as a case report by Fenton *et al*,[12] describing the need for its removal under general anaesthetic due to the risks of complications associated with retained foreign bodies in subcutaneous bone. The only paper that demonstrates higher complication rates is from an online questionnaire sent to members of the Danish Society for Emergency Medicine that gathered experiential data from 1802 clinical cases of IO access to establish the complication rates of its use.[25] Commonly reported complications with establishing IO access were patient pain/discomfort (7.1%), difficulties with penetration of periosteum with the needle (10.3%), difficulties with aspiration of bone marrow (12.3%) and bent/broken needle (4.0%). Once IO access is established, the reported complications were difficulties with injection fluids and drugs (7.4%), slow infusion despite use of pressure bag (8.8%), displacement after insertion (8.5%) and extravasation (3.7%). Compartment syndrome and osteomyelitis occurred in 0.6% and 0.4% of cases, respectively. This study was based on users' recollection of events rather than a review of patient databases; therefore, there was an obvious risk of

recall bias, which could explain these higher than expected complication rates.

A full economic analysis is out-with the remit of this report, but nevertheless it should be considered that cost is a potential barrier to replacing intravenous with IO access. EZ-IO needle sets contain three different-sized needles, costing around £65 per set. In addition to this, EZ-IO also requires an initial outlay of about £225 per battery-powered driver, although each driver generates over 1000 needle insertions. FAST1 devices are single-use devices, each costing about £95. An intravenous cannula and dressing is in the order of £1–2, and it is for these reasons it can be assumed IO use is unlikely to supersede intravenous access for routine use. However, we feel it should still be considered as an alternative for patients in extremis especially when peripheral attempts have failed and should be widely used throughout emergency departments in the UK. Emergency departments and prehospital care teams should consider investing in and training staff on the use of IO access for these situations when peripheral access is unobtainable.

LIMITATIONS

Although the database has been accessed retrospectively, the data capture is prospective, a robust system using trained dedicated staff, the TNC, to ensure accuracy of information. The principal source of bias might be the loss of data from the frontline. Although handover is carefully choreographed at every level, and all paperwork, including scraps of notes, are kept, it is entirely possible that IO access failures on the frontline may not be recorded. However, evidence of failed IO access should be noticed by the receiving team in the hospital, and if the patient were conscious at the time, they might report this to the TNC at subsequent interview so that the frequency of unrecorded attempts is thought to be low. The patient population is a mixture of military and civilian with a wide range of ages and injuries, which means that the findings can be applied to other adult trauma populations. It is possible that complication rates may be different in the non-trauma population; however, the overall safety and success of the technique must still be emphasised.

CONCLUSION

Current guidelines[3 4] suggest that if intravenous access cannot be established within the first 2 min of resuscitation, only then should one *consider* gaining IO access. We propose, in light of the fact that IO access can be gained faster than venous cannulation, with ease and limited complications and can be safely used to administer a wide variety of life-saving products, that guidelines be reconsidered. In particular in the prehospital environment and in severely injured trauma patients, we feel the IO route should be considered as a primary method of obtaining vascular access.

Overall our findings support and build on previous evidence in adult and paediatric patients that IO access is a safe and effective method of obtaining vascular access in critically ill patients, especially in the trauma population. It has been a key intervention that has been part of the revolutionised care delivered by the Defence Medical Services, allowing prompt delivery of analgesia, anaesthetic agents, fluids and blood products. It is simple to use, requires minimal training, has a high success rate and low-complication rate, and is used by various different personnel, including medics, paramedics, nurses and doctors, in various different and challenging prehospital and hospital environments. The ability to use these devices in various situations makes IO access a valuable tool in the end-to-end trauma system; the same technique can be used at any point along the patient journey. We conclude that IO devices should be made widely available for use in the critically ill adult trauma patient.

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