# Vascular Access on the 21st Century Military Battlefield

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## Abstract

**Timely and appropriate access to the vascular circulation is critical in the management of 21st century battlefield trauma. It allows the administration of emergency drugs, analgesics and rapid replacement of blood volume. Methods used to gain access can include; the cannulation of peripheral and central veins, venous cut-down and intraosseus devices. This article reviews the current literature on the benefits and complications of each vascular access method. We conclude that intraosseus devices are best for quick access to the circulation, with central venous access via the subclavian route for large volume resuscitation and low complication rates. Military clinicians involved with the care of trauma patients either in Role 2 and 3 or as part of the Medical Emergency Response Team (MERT), must have the skill set to use these vascular access techniques by incorporating them into their core medical training.**

## Introduction

Timely and appropriate access to the vascular circulation is critical in the management of 21st century battlefield trauma. This essential procedure allows the administration of emergency drugs, analgesics and rapid replacement of blood volume using crystalloid, colloid or blood products. It encompasses the cannulation of peripheral and central veins, venous cut-down and intraosseus (IO) devices.

The type of access employed in any given situation will be determined by the skill of the operator, the environment in which it is used, the degree of hypovolaemic shock and the extent and pattern of injury. Gaining access to the human vascular system has been practised for millennia, most notably for bloodletting procedures believed to improve health [1, 2]. IO access was first documented by Drinker in 1922 [3], but it was during the Second World War that IO infusions were more widely used to resuscitate patients in haemorrhagic shock [4]. After the war, it's use largely died out in the adult population, but has seen resurgence during the Iraq and Afghanistan conflicts with the introduction of modern needle and introducer systems [5].

The Sapheno-femoral venous cut-down was popularised during the Vietnam conflict to manage casualties with severe haemorrhagic shock [6].

During the recent conflict in Iraq and Afghanistan the use of large bore central venous access (Figure 1) has been popularised by experienced military trauma clinicians. This has been driven by the severity of today's battlefield casualties and the requirement for large volume fluid resuscitation. This is often used in conjunction with the transfusion protocol advocated by Borgman and colleagues [7] using the ratio of 1 bag of red cells: 1 bag of plasma in the shocked trauma patient [8-11].

## Flow

Flow through a vessel or tube is determined by Poiusselle's equation describing laminar flow:

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***Figure 1: Size 9 French Cook Introducer central venous catheter which can be used for high volume fluid resuscitation***
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$$Q = \frac{\Delta P \pi r^4}{8\eta l}$$

**Q** = Flow rate ml/min, **P** = Pressure gradient between the proximal and distal ends of the tubing, **r** = radius of the tube, **η** = viscosity, **l** = length of the tube.

Importantly, if you double the diameter of the cannulae, the flow rate increases by a factor of 16. To aid flow, the venous cannulae and connecting tubing must be short and wide, the fluid administered warm, pressurised and the viscosity of the fluid reduced [12]. Although Poiseuille's law demonstrates the principles of flow, the actual flow rate of fluid under pressure is determined by a quadratic equation which takes into account the development of turbulence. Barcelona et al surmised that this partly explained why even large bore catheters are not capable of delivering the flows predicted using Poiseuille's equation [13].

| Device | Internal Radius (mm) | Length (mm) | Flow Rate Gravity ml/min (3.2mm tubing) Hartmann's/ $H_2O$ | Flow Rate 300mmHg ml/min (3.2mm tubing) Hartmann's/ $H_2O$ | Flow rate 300mg ml/min (5.0mm tubing with filter) Blood | Level 1 Infuser (300mm Hg) Ml/min Hartmann's | Rapid Infusion System (approx 285mm Hg) ml/min Hartmann's |
|---|---|---|---|---|---|---|---|
| 20G venflon | 0.423 | **32**-33 | 40 - **67** | n/a | n/a | 140 | 144 |
| 18G Venflon | 0.515 | **45**-52 | **103** | n/a | n/a | 209 | 205 |
| 16G venflon | 0.705 | **45**-55 | 151+/-3 - **236** | 448+/-19 | 444+/-25 | 368 | 412 |
| 14G venflon | 0.895 | **45**-64 | 194+/-5 - **270** | 577+/-22 | 779+/-39 | 488 | 584 |
| 10G Angiocath | 2.25 | 76.2 | 162 | 496 | 1,248 | n/a | n/a |
| 8 French | 2.2 | 160.02 | 162 | 492 | 1,200 | n/a | n/a |
| 8.5 French (Arrow) | 1.43 | 112 | 245+/-4 | 645+/-20 | 1,622+/-120 | 596 | 857 |
| Sternal IO (FAST) | n/a | **6** | 17.9+/-9.1 **(30-80)** | 104.1+/-46.5 - **125** | n/a | n/a | n/a |
| Tibial IO EZIO | **15G** | **25 Paed 15** | 68-73 | 165-204 | n/a | n/a | n/a |
| Humeral IO EZIO | **15G** | **25 Paed 15** | 81-84 | 148-153 | n/a | n/a | n/a |

***Table 1: Flow rates of vascular devices [12- 17] – The manufacturers' details are marked in bold.***

## Intraosseous Access

Many British casualties from the recent conflicts in Iraq and Afghanistan present with severe haemorrhagic shock associated with multiple traumatic limb amputations from improvised explosive devices. In these situations IO can be utilised with substantial effect. The intravenous (IV) or IO route is now accepted as first line access in paediatric resuscitation by the UK Resuscitation Council [18]. The Defence Medical Services (DMS) currently have two IO systems in place; The EZ-IO® and the FAST 1®.

### *EZ-IO® System*

The EZ-IO® system (Vidacare, SanAntonio,USA) was introduced into UK DMS in December 2006. It consists of a battery powered disposable drill, a bevelled, hollow needle with a cutting needle central trocar and a short connection tube (with a one way valve) for fluid /drug administration. There are three needle sizes and the insertion point is just below and medial to the tibial tuberosity on the upper flat aspect of the tibia. EZ-IO can also be inserted into the lateral aspect of the humeral head or iliac crest. Contraindications are rare, but EZ-IO should not be inserted into a fractured bone to avoid extravasation into soft tissues or through infected tissue.

### *FAST 1 IO*

The FAST 1® sternal IO device (Pyng Medical Corporation, Richmond Canada) is designed exclusively for use in the manubrium sternum (Figure 2) and has advantages of rapid, easy to locate placement, reasonable flow rates (Table 1), can be used during cardio-pulmonary resuscitation and has low risk of dislodgement. The device is not MRI compatible and is contraindicated in sternal fractures.

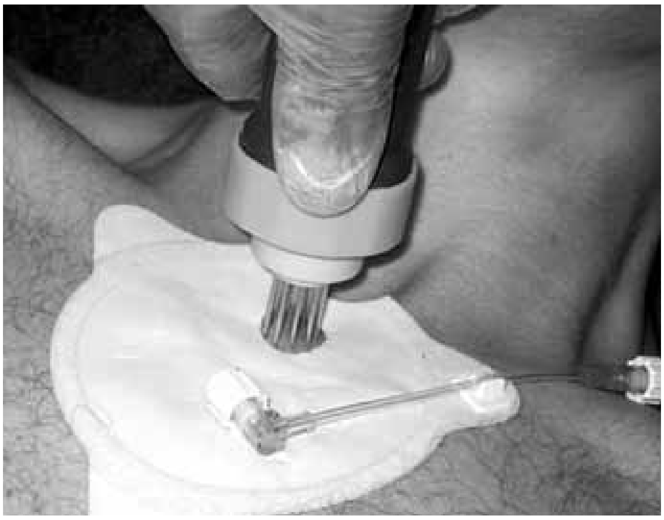

***Figure 2 : Photo of FAST 1® sternal insertion.***
*With kind permission from Trauma.org*

Using the adhesive guide, the FAST is inserted perpendicular to the manubrium made possible by the 10 guide needles surrounding the I/O which will only release the cannulation mechanism when the pressure in all 10 needles is equal. The rationale for having 2 different IO systems is that multiple ballistic or fragmentation limb injuries are common and may preclude the use of EZ-IO. However, the large ballistic chest plate usually protects the sternum. Teaching is simplified by indicating that FAST1 is only for sternal placement and the EZ-IO for anywhere but the sternum. In the authors' experience the preferred sites of IO access are ideally tibial, then humeral followed by sternal.

### *Complications*

Operation of the EZ-IO device is intuitive and insertion times are fast with most operators being able to insert an IO in less than 10 seconds. Published DMS experience involving EZ-IO for vascular access for 26 patients demonstrated 97% effective function. No complications of infection were noted, but pain was observed in responsive patients with the pain of infusion exceeding that of their underlying injuries in three cases [5]. This was also reported by Davidoff et al who noted the average pain upon fluid infusion was rated as '5' on a modified visual analogue scale (1-10) [19]. From the authors experience this is indeed correct, however pain decreases markedly after completion of the first fluid flush.

Frascone et al evaluated provider performance for obtaining IO access with the FAST1 and the EZ-IO and noted that 72% of FAST1 and 87% of EZ-IO were successful. EZ-IO (p=0.009) [20]. An interesting study was performed by Suyama et al comparing EZ-IO and peripheral intravenous cannulation in full personal protective equipment simulating a Chemical-Biological-Radionuclear (CBRN) environment. In all the scenarios the IO was found to be both faster and easier at gaining access [21].

The most notable and recent complications with the FAST1 have involved difficulty in removing the needle, some of which required surgery in order to extract. The device has apparently been modified so that no removal tool is required and the infusion tube can be pulled out by hand [22]. Although the observed risk of infection is low, this can take the form of cellulitis or in more severe forms osteomyelitis [23]. When the tibia is used as an IO site it has been reported that occasionally fluid resuscitation can lead to compartment syndrome in children [24].

Other potential but not as yet reported complication is the use of the IO in patients with an unstable pelvis. In the authors opinion the practice of insertion of IO's in patients at high risk of pelvic instability (Blast/Blunt trauma from victim operated explosive device) is potentially dangerous and should be discouraged. Misplacement of IO's also seems to be increasingly common especially with the humeral approach. Common causes for this are: haste, patient movement on transfer, lack of training and not doing the 'wiggle test' (if the IO wiggles it's not in).

## Peripheral venous access

Combat medics, nurses, doctors and other health professionals are trained to place intravenous peripheral cannulae. An experienced practitioner takes a mean of two minutes to cannulate a patient in the Emergency Department [25] , but in a case series over 120, 000 procedures, gaining intravenous access (IVA) in the pre hospital setting was associated with an increase in on-scene duration of between 3.17 - 5.4 minutes [26].

### *Site*

Peripheral venous cannulae are usually sited in the dorsal metacarpal veins, tributaries of the basillic and cephalic veins in the forearm or ante-cubital fossa. The external jugular vein may also be utilised in arrest situations [27]. Battlefield advanced trauma life support (BATLS) recommends that two attempts should be made to secure two 14G cannulae [28]. In cases of severe multi-trauma in which occult thoraco-abdominal damage is suspected, it is recommended to secure IV access both above and below the diaphragm and as close to the heart as possible. These measures attempt to secure a route to deliver fluid and medications to the central circulatory system with minimal risk of disruption [29]. IV access should ideally not be placed in limbs with massive oedema, burns, sclerosis, phlebitis, thrombosis or on the side of radical mastectomies. Cannulation at sites of cellulitis or extremities with shunts or fistulas should be avoided because it may cause bacteraemia or thrombosis [30].

### *Complications*

Common complications include bruising, irritation, failure, haematoma, thrombophlebitis and extravasation of fluids or drugs causing pain and irritation to the surrounding tissue [29].

### *Tricks*

Methods to increase peripheral venous distension include asking the patient to open and close their fist, light tapping of the vein, lowering the arm below the level of the heart and heat packs applied for 10 to 20 minutes [30]. A technique for up-gauging peripheral venous cannulae in volume resuscitation has been described whereby an initial small cannulae is inserted into a limb, and whilst the tourniquet remains up, 30-50mls of saline is injected into the veins via this cannulae. This then allows a large bore cannulae >18G to be inserted into the same limb [31]. Small cannulae can also be up gauged using a Rapid Infusion Catheter which employs the Seldinger (guidewire) technique.

The use of Ultrasound (US) guided peripheral IVA has shown to be of use and superior to external jugular IVA in the Emergency Department when IVA is difficult [32]. A review of the literature has shown that it requires less time, decreases the number of skin punctures and improves patient satisfaction [27].

## Venous Cut-down

The practice of peripheral venous cut-down has declined due to the efficiency of the Seldinger technique for central venous access and limited clinician exposure [33].

However, in the profoundly hypovolaemic trauma patient where there may be distorted central anatomy, lack of femoral pulses and scarring of peripheral veins, it remains a useful tool. It enables reliable vascular access to be obtained with direct vision of the vein and reduces cannulae misplacement.

Westfall found that in shocked trauma patients, venous cut-down took longer to perform than inserting a femoral 8.5French Central Venous Catheter (CVC) with a mean of 5.6 and 3.2 minutes respectively. The cut-down also had a decreased flow rate (150ml/min compared to 219ml/min for CVC) [34]. Venous cut-down sites include the proximal and distal greater saphenous vein, the cephalic and basillic veins.

The most commonly used access is the greater saphenous vein proximally in the groin because of its large diameter and ease of dissection.

This can be reliably located 5cm distal to the junction between the middle and medial one third of the imaginary line between the anterior superior iliac spine and the pubic tubercle or by the "Rule of Two's"; two fingerbreadths below and lateral to the pubic tubercle. These points form the midpoint of a 5cm horizontal incision which can also be approximated by a 5cm horizontal incision starting just distal to where the labia/scrotal fold meet the thigh [35]. A vertical venotomy in the vein can allow the passage of a straight wire (within the dilator) within the 8.5F CVC.

Absolute contraindications are major blunt or penetrating trauma to the ipsilateral groin or limb. Complications occur in 2-15% of cases and include haemorrhage, damage to the femoral artery and nerve, wound infection and dehiscence, thrombo-embolism and phlebitis [33].

## Central Venous Access

The first central venous catheter was pioneered by a German surgeon in 1928 who described advancing a plastic tube near the right atrium using his own left ante-cubital vein [36]. Aubaniac followed, when he described the insertion of a catheter using the subclavian vein [37]. The technique was improved by the Swedish radiologist, Seldinger in 1953 with use of a guidewire whose technique we still use today [38].

Obtaining central venous access is important to military clinicians as it is not only the most effective route for administering emergency drugs [39, 40], but is the quickest and most effective means to resuscitate haemorrhagic shock in trauma patients with a relatively low complication rate [41]. The 8.5F Swan introducer sheath for a pulmonary artery catheter (Figure 1 and 3) is commonly used for this purpose, delivering high volumes under pressure quickly (Table 1) [12, 41].

### *Site*

In the trauma setting, cannulation of the internal jugular vein is often impractical due to neck collar and blocks for C-spine protection. Also, in severely hypovolaemic casualties the internal jugular vein (IJV) collapses and therefore increases the risk of carotid puncture as 54% of people have their IJV overlying their carotid artery [42].

***Figure 3 : Photo showing the insertion of a left sided subclavian central venous trauma line (the light blue plastic tube placed on the end of a blue syringe in the operators right hand).***

*With kind permission of Major R Dawes.*

The subclavian vein is large and anatomically easy to locate in the face of hypovolaemia and so makes an ideal candidate for use in the trauma setting [11]. Subclavian lines should be placed on the ipsilateral side in the presence of penetrating trauma to chest wall, pneumothorax or haemothorax [8, 43]. Femoral vein cannulation may be complicated by arterial puncture if there is no palpable femoral pulse [44]. It should be avoided in ipsilateral limb or presumed inferior vena caval injury to avoid extravasation [8, 44].

### *Complications*

Controversy over the use of CVC's in trauma casualties exists because of the perceived increase in complication rates. Complications include haematoma, arterial puncture, haemo/pneumothorax, malposition of the catheter, air embolism, line sepsis, thrombosis, embolism and thrombophlebitis. The most common complications in IJV catheterisation are arterial puncture, and pneumothoraces with subclavian cathterisation [8, 41]. Abraham et al [45] and Ferguson et al [43] suggest that success rates are lower and complication rates higher (14% and 15% respectively) in emergent CVC placement in trauma patients. The decrease in central blood volume following haemorrhage and potential venous anatomical changes in trauma patients may complicate the technique [9].

However Pappas et al found no significant difference in complication rates (7.8%) between trauma patients irrespective of the degree of shock [10]. Scalea et al [9] noted that even in the presence of hypotension (<90 mmHg) there was no statistical difference in the time taken to obtain central venous access (1.9 mins), the number of attempts (1.8) or complication rates (4%). Schwab had a 2% complication rate in 100 subclavian CVCs placed in patients with class III or IV haemorrhage [46]. In a recent large pre-hospital study (n=497), CVCs were inserted for resuscitation in 2.0+/-0.5 min, with a mean of 1.3 attempts and a 6.9% complication rate [40]. Of note, 35% of these patients were in cardiac arrest.

Insertion of CVCs by inexperienced practitioners result in more than double the rate of complications (11%) compared to experienced practitioners (5.4%) [47]. Complication and failure rates increase as the number of cannulation attempts increases, making it unlikely after five unsuccessful needle passes [48].

Authors recommend that CVCs placed during resuscitation should be changed within 24 hours to avoid line sepsis and thromboembolic complications [10, 12, 33, 34].

### *Tricks to improve efficacy*

A technique has been described using bilateral subclavian 8.5F catheters in severely shocked trauma patients. This technique allows venous return to be maintained despite a large vascular defect. Rapid disconnection must be avoided as this may lead to fatal air embolism or exsanguination [49]. This method of rapid fluid resuscitation must be tempered, as the flow rate may easily exceed the ability of the heart to process the volume. Fluid must never be given without clinical re-assessment and an upper limit of 250mls as a bolus is standard in the pre-hospital military setting. Pressure, cardiac contractility and volume status must then be evaluated before the next rapid fluid bolus given.

The literature suggests that US guided CVCs improve success rates and decrease the time of insertion and complication rates [27, 41, 42]. This is echoed by the National Institute of Clinical Excellence (NICE) guidelines which encourage US use in both elective and emergent CVC [50]. Use of US in the field depends on availability and serviceability of equipment and the environment in which it is employed i.e. aircraft. The landmark technique for CVC should therefore remain at the fore- front of the military clinician's armamentarium.

## Discussion

In many patients IV therapy cannot be initiated because of inadequate access to peripheral veins. This lack of vascular access delays the resuscitation process and limits the benefit of medical intervention due to late administration of medications [51]. Both speed and overall success of vascular access are important when evaluating potential methodologies for their use in the pre-hospital and hospital environment.

In critically ill paediatric patients, vascular access may present substantial difficulties [52]. IO access will provide a significant time saving which will benefit critically ill trauma patients, both by decreasing the time to achieve access and time to drug administration. In 2005 the American Heart Associations' resuscitation guidelines were updated to reflect this and now recommends the IO route be the first alternative to difficult or delayed intravenous access [53]. From Table 1 it is clear that if rapid fluid resuscitation is required, then large bore IV access via the central route is preferable. However, there is anecdotal use of multiple IO access ports to achieve increased fluid administration.

Current medical training is heavily weighted towards theoretical rather than practical training. Placing IV cannulae in haemodynamically unstable casualties with multiple limb amputations is very challenging even for experienced clinicians in ideal situations. This should be balanced against IO insertion which is rapid, intuitive and requires minimal training and in less than ideal environments.

The current Gold Standard for resuscitation is the subclavian large bore 8.5 French 'Trauma Line'. It provides rapid access, fast flowing large volume fluid resuscitation. This technique however requires skill and training which currently only a limited number of specialities provide. The authors feel this should be updated and become a core competency for military clinicians involved in the management of severely injured trauma casualties providing advanced resuscitation on the Medical Emergency Response Team (MERT) Role 2 and 3 hospital setting.

## Conclusion

Vascular access in the military polytrauma patient is difficult and can take up precious time that could be used for fluid resuscitation and drug administration.

The authors propose that to avoid delay initiating resuscitation in pre-hospital or hospital setting, the IO approach should be the first line vascular access in casualties with severe trauma. This is then to be augmented by two large bore peripheral cannulae or ideally an 8.5F central venous catheter in the subclavian vein depending on the experience of the practitioner and the severity of the injury.

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