1079-6061/97/4202-0288$03.00/0
The Journal of Trauma: Injury, Infection, and Critical Care

Vol. 42, No. 2
Printed in the U.S.A.

Bone Marrow Infusion in Adults

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Objective: **To asses the feasibility and success rate of vascular access through intraosseous infusions in adults, in elective and emergency situations using a novel, automatic device, the bone injection gun.**

Design: **A prospective, nonrandomized trial.**

Materials and Methods: **Two groups of patients were prospectively selected over an 11-month period. Group 1: Adult patients with recent closed long bone fractures, who underwent orthopedic surgery to upper and lower limbs and needed regional anesthesia. Group 2: Adult patients who required emergency or semiemergency vascular access, in whom intravenous central or peripheral cannulation could not be established within a reasonable period of time.**

Main Results: **Fifty adult patients, aged 27 through 78 years, underwent the procedure, which was universally successful. In group 1, n = 31 patients; in group 2 (n = 19), 12 patients had multiple injuries, and seven underwent emergency resuscitation. In 76% of the cases, the needle was inserted into the area of the tibial tuberosity; in the reminder of the cases, the needle was inserted at the distal end of the radial bone and into the lateral or the medial malleolus. The success rate for an adequate insertion was 100% in this group of patients. No complications from the procedure were observed in this series.**

Conclusions: **This study emphasizes the importance and feasibility of the intraosseous route for infusion of fluids and medications in emergency situations in adults. The use of an impact, high speed automatic needle insertion device provides a higher success rate of vascular access via the intraosseal route in adult patients.**

Key Words: **Intraosseous infusions, Bone marrow infusions, Bone injection gun, Intraosseal Regional anesthesia, Osteoclysis, Intravascular access.**

Vascular physiology of bone and intraosseal infusions (IOI; bone-marrow, intramarrow infusion) were first described by Drinker et al. in 1922.[1] In 1941, the method was introduced for clinical use by Tocantis et al.,[2,3] mainly in children. Bone-marrow transfusion was practiced in Great Britain[4–6] and in South America for emergency cases in the 1940s.[7] In the Former Soviet Union, the intraosseous route was used in the 1960s for injection of local anesthetics.[8–9] Intraosseal regional anesthesia is a tested and efficient method originally described by Thorn-Alquist[10] and further developed at the Carmel Medical Center.[11] The insertion of an emergency intravenous (iv) canula in children and adults may be a difficult, time consuming procedure, especially when performed by inexperienced medical personnel, who frequently fail to establish it. The need for minimum time spent in the field, and the benefit of rapid transportation to the trauma center without time wasted by multiple attempts to place an iv line, is extensively discussed in the current literature.[12–14]

In emergency situations such as air and road transports of severely compromised patients and mass casualties from accidents, fires, or explosions, it may be difficult, even for experienced physicians, to gain iv access. In these situations where the establishment of an effective vascular access is imperative, the intraosseous (io) route is indicated. Vascular access via the io route is recommended for use in emergency situations in children by the American Heart Association, the American Academy of Pediatrics,[15] and The American College of Surgeons[16] when venous access is not immediately possible. It is also suitable for use in premature babies, term neonates, infants, children, and adults[11,13,14,17–25].

The advantages of using the io route have been studied in acutely ill children and adults in the prehospital setting.[13,22,23,26] Highest rates of success were demonstrated in children younger than 3 years old (85%) and the lowest rates in children over 10 years old and in adults (50%). The main causes for failure in this series were errors in landmark identification and bending of the needles.[23]

Our hypothesis in this study is (1) the io is an effective and accurate technique to gain intravascular access in adults in emergency cases, and (2) that the use of an automatic device for the insertion of the io trocar may improve the success rate for this route in adult patients.

MATERIALS AND METHODS

Emergency IOI and intraosseal regional anesthesia were performed using a novel automatic device, for insertion of a 15-gauge trocar needle into the bone marrow, the bone injection gun (BIG- TEIC Ltd. Science Park Technion, Nesher. Israel). The use of this device for use in intraosseal regional anesthesia was briefly described in a previous publication.[10]

The patients selected for this procedure were prospectively characterized into two groups: group 1, adult patients with recent closed fractures or elective surgery of the limbs (distally to elbow and knee joints) who needed regional anesthesia to receive orthopedic treatment (Table 1); group 2, adult patients who required emergency or semiemergency vascular access, in whom iv central or peripheral infusion could not be established in a reasonable period of time, considered as 10 minutes.

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TABLE 1. Limb surgery classification performed using the bone injection gun for administration of intraosseal anesthesia

Type of Surgery	No. of Patients	Average Age	Male/ Female
Hand fractures, dislocations, Colles fractures, ORIF[a]	5	51	1/4
Elective hand surgery	3	37	2/1
Fracture dislocation forearm and elbow, ORIF	1	38	1/0
Elective surgery of the knee joint	2	31	1/1
Fracture–dislocation of the foot and ankle, ORIF	6	57	1/5
Elective surgery of the foot	14	62	3/11
Total	31		

[a] ORIF, open reduction internal fixation.

The preferred anatomic point for insertion of the trocar needle was an area 1 to 2 cm medial and 0.5 cm above the tibial tuberosity. Other recommended points for insertion included the distal end of the radial bone in the upper limb (posterior–distal metaphysis of the radius, opposite to the radial pulse area), proximal metaphysis of the humerus, and the lateral or medial malleolus in the lower limb, 3 to 4 cm proximally to the distal tip of the malleolus. The needle could also be inserted into the ulnar styloid, the distal epiphysis of the second metacarpus, or the distal epiphysis of the first metatarsus in adult patients. Sternal punction was not recommended due to the possibility of penetration to the mediastinum. For the purpose of this study, the use of this device was restricted to specifically trained personnel.

The depth of penetration for the trocar needle using the BIG could be adjusted, according to the anatomical area chosen for the injection. For example, for adults, to gain io access in the proximal tibial metaphysis (around the tibial tuberosity), the recommended depth of penetration is 2.5 cm. Above the medial malleolus, the depth is 2 cm. In the lateral malleolus and in the distal metaphysis of the radius, 1- to 1.5-cm depth is recommended.

Technique of Insertion

According to the area selected for the injection, the depth of penetration is adjusted by unscrewing the sleeve from the cylindrical housing (Fig. 1*A*). The skin area is thoroughly cleaned with an antiseptic. The front part of the BIG is placed in a perpendicular position to the site of injection, holding firmly, the safety pin is pulled out. The trigger is then pressed, and the sterile trocar is inserted into the bone at high speed, propelled by a powerful, precharged coil (Figs. 1*B* and 2). The stylet trocar is then manually separated and only the needle cannula remains stocked in the bone. The needle is then connected to a syringe (Fig. 1*C*) or to a standard iv tubing, with an external pressure bag or pressure device delivering 300 mm Hg to the solution bag.

To minimize pain induced during the initial infusion of fluid under pressure to the bone marrow in conscious patients, two steps were recommended before the infusion: first, withdrawal of 2 to 5 mL of bone marrow, and second, the slow injection of 2 to 5 mL of 1% lidocaine over 60 seconds. Both recommendations could be used sequentially if desired.

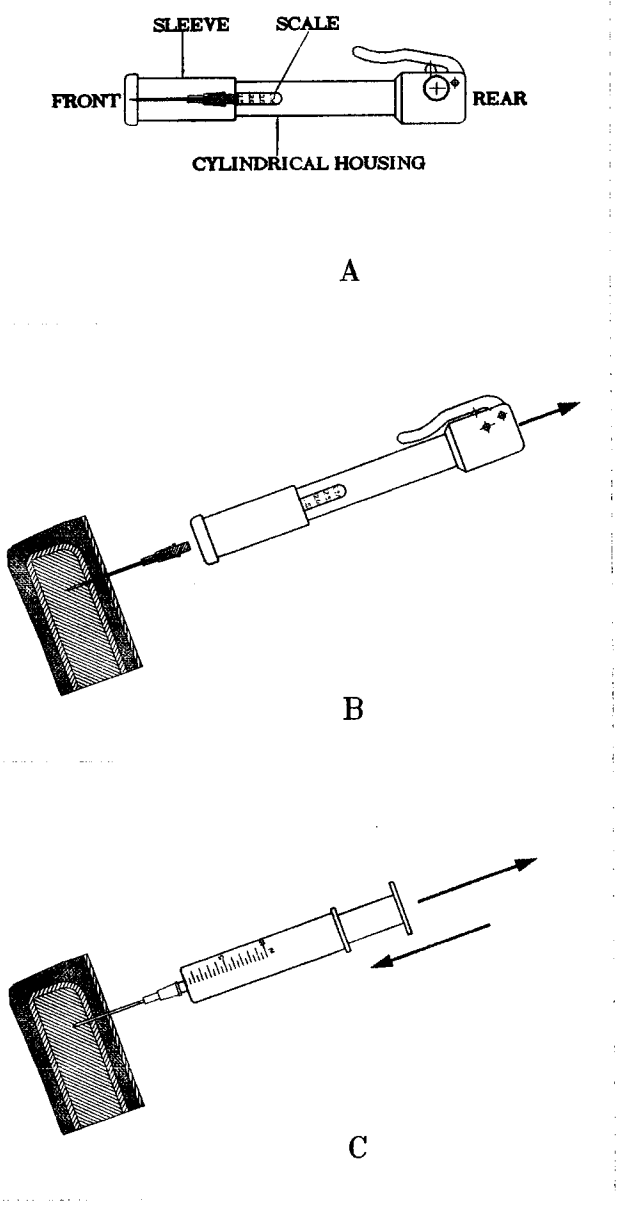

FIG 1. **(*A*) The bone injection gun (BIG) in locked position. (Reproduced with permission from the TEIC-Technion Entrepreneurial Incubator Co. Ltd., Science Park, Technion, Nesher, Israel.) (*B*) After triggering and impact insertion in the bone, the BIG's housing separates from the trocar-needle. (*C*) The needle after removal of the stylet, inserted into the bone marrow and connected to a syringe.**

There were no contraindications to the insertion of an io needle in emergency or elective situations except that the trocar should not be inserted into an infected area, an open fractured bone, or into a known bone tumor lesion. We do not consider osteoporosis or osteopetrosis to be contraindications.

RESULTS

In a period of 11 months, 50 patients (age range, 27–78 years) underwent the bone-marrow infusion procedure, 47 at the Carmel Medical Center, and three during prehospital care.

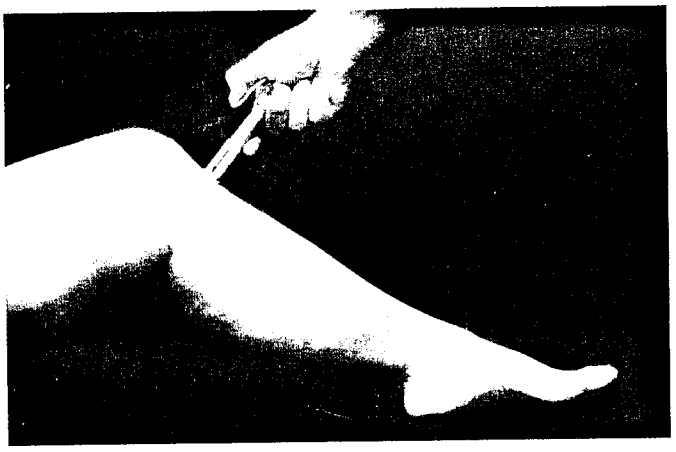

FIG 2. The bone injection gun in position before trigger release.

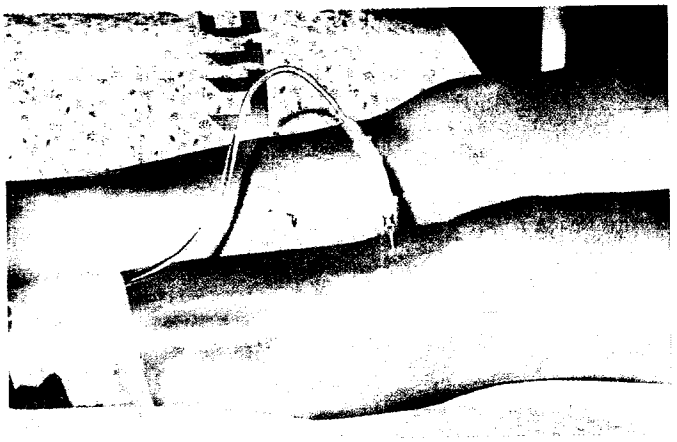

FIG 3. The needle in place, medial to the tibial tuberosity, and connected to a standard infusion set.

Insertion of the needle using this method was successful in all cases. The time required to perform the bone-marrow infusion, from the moment of the decision, until the infusion was established, was 1 to 2 minutes.

In group 1, 31 patients underwent the procedure electively (Table 1). In group 2, there were 12 patients with multiple injuries admitted to the emergency department or treated at the scene by medical rescue staff and establishment of an iv infusion was unsuccessful after 10 minutes; seven patients required emergency resuscitation and/or emergency vascular access in medical emergency situations.

These seven patients had an initial median systolic blood pressure (BP) of 73 mm Hg and initial median pulse rate (PR) of 94/min. After 1 hour, BP was 95 and PR 80, and after 2 hours BP was 90 and PR 85. Two of these seven patients died after 2 hours; four of them were extremely obese, presenting a difficult challenge for iv placement. The remaining 12 patients from group 2 registered an initial median systolic BP of 85 mm Hg and PR of 120/min. After 1 hour, BP was 100 and PR stood at 112, and 2 hours later BP was 100 and PR 97. All required fluid and/or emergency drug therapy. Data on individual patients are presented in Table 2.

In 76% of cases, the trocar needle was inserted into the area of the tibial tuberosity (Figs. 3 and 4). In the remainder, insertion took place in the upper limb, at the distal end of the radial bone, and in the lower limb, into the lateral or medial malleolus (Table 3). In group 2, once the patient's cardiovascular and general conditions improved or permitted, additional iv lines were placed. The IOI was kept in place for 1 to 6 hours. In one case, the needle was removed after 6 days (case 4, Table 2, Fig. 5). No local or systemic complications from the procedure were observed in this series in a follow-up of x-ray films and clinical observations for 4 months in the 31 patients of group 1, and for a period of up to 24 hours in group 2.

TABLE 2. Data on 19 patients treated with emergency intraosseous infusion using the bone injection gun

Patient	Diagnosis	Age	Sex	Systolic Blood Pressure		
				Initial	1 hour	2 hours
1	Cardiogenic shock resuscitation	74	M	73	95	80
2	Cardiogenic shock resuscitation	78	M	80	100	100
3	Cardiogenic shock resuscitation	77	F	70	D[a]	—
4	Cardiogenic shock resuscitation	74	F	70	80	70
5	Empyema, septic shock	75	F	92	115	115
6	Massive pulmonary embolism	69	F	60	90	D
7	Thyroidectomy, intraoperative dislodged CVC[b]	31	F	90	120	120
8	Multiple trauma (chest and abdominal), MVC[c]	27	F	85	100	100
9	Chest contusion - MVC	45	M	70	82	120
10	Femoral neck fracture, congestive heart	72	M	115	120	100
11	Fracture of pelvis, retroperitoneal hematoma	45	M	65	90	90
12	Multiple rib fractures - MVC	38	F	80	135	130
13	Fracture of pelvis, dialysis patient	77	M	75	90	80
14	Fracture of femur, dialysis patient	74	M	130	130	135
15	Fracture of L-1 vertebrae, asthmatic	37	M	110	120	120
16	Fracture of L-1 vertebrae, paraplegia	39	M	95	95	110
17	Bilateral femoral fracture - MVC	42	M	70	110	90
18	Fracture of pelvis - femur - MVC	35	F	85	80	100
19	Intertrochanteric fracture, terminal disease	72	M	120	100	90

[a] D, died.
[b] CVC, central venous catheterization.
[c] MVC, motor vehicle collision.

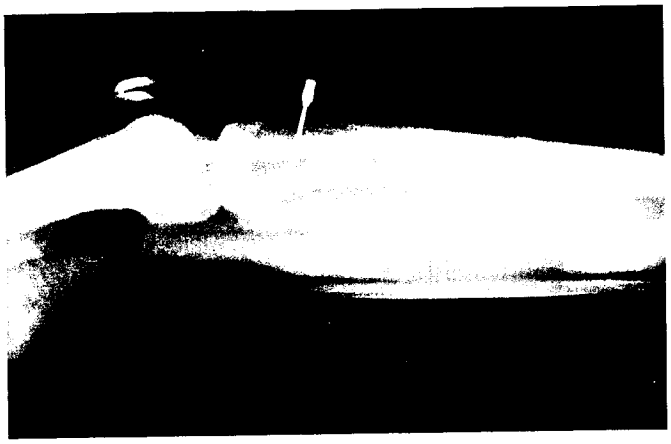

FIG 4. **X-ray film of the same patient (drug addicted, 31 years old) complicated with pneumothorax after unsuccessful central venous catheterization.**

Infusion rates (Table 4), were measured in patients in whom the needle was inserted in the tibial region. In seven patients of group 1, the flow rate of the injection of lidocaine–saline solution was measured using manual pressure to a syringe connection. In group 2, the infusion rate, using Ringer's solution, was measured in 11 patients (nine trauma patients and two medical emergencies). The infusion rate for whole blood was measured in three of the trauma patients that presented acute anemia and were hemodynamically unstable (hypotensive and tachycardic) after crystalloid infusion. Flow rates were measured during 10 minutes, using a 15-gauge needle, and 300 mm Hg pressure was applied to the infusion bag.

DISCUSSION

We have demonstrated that the use of a impact penetration of a trocar needle into the spongeous bone, improved success rate of vascular access and minimal pain when trying to establish intraosseous infusions. All current methods for injection of fluids into bone marrow are based on the io insertion of a trocar needle into the long bones, iliac crest, or sternum.[18–21] The fluid injected into bone marrow disperses via its venous drainage which connects the bone marrow to systemic circulation (Fig. 6) even in the adult with a much less active bone marrow than young children, but with a patent sinusoidal vascularity.

Despite the fact that the technique of io access has been known for many years, most physicians are unaware of its existence or avoid using it for various reasons. The latter include a lack of suitable training and fear of complications such as infection or causing pain during the insertion of the trocar needle.[21–23,26–28] The main complication of IOI previously encountered was osteomyelitis due to lack of aseptic technique. For all the above reasons and the increased use of the iv canula, the use of io route for vascular access was abandoned for many years. However, there have been occasional reports in recent years that describe the use of this route as a life-saving procedure, especially in infants and children.[22,23,26,29–32] On many occasions, this technique is used only as a last resort, following the inability to successfully access a peripheral or central vein in an emergency.

During simulated mass casualty events and simulated nu-

FIG 5. **Osteoclysis in the tibia of a 74-year-old woman in a successful resuscitation case. The needle was removed after 6 days without complications.**

TABLE 3. **Area of intraosseal bone marrow needle insertion in 50 patients**

Anatomical Location	Group Selection	No. of Patients	Percent from Total
Tibial tuberosity	1	21	42
	2	17	34
Distal end of radius	1	9	18
Medial malleolus	2	2	4
Lateral malleolus	1	1	2

TABLE 4. **Intraosseal flow rate infusion (using Ringer's solution)**

Pressure	Needle Gauge	Volume/minute (mL/min)
Gravity pressure[a]	16	5–10
300 mm Hg	16	15–20
300 mm Hg	15	30–40
Syringe connection[b]	15	60–100

[a] Infusion bag 80 cm above chest.

[b] Using maximal manual pressure with continuous sequential aspiration from a bag and injection to the bone marrow through a three-way valve attached to a standard infusion bag. Whole blood infusion achieved 50–60% of the flow rate of crystalloid fluids.

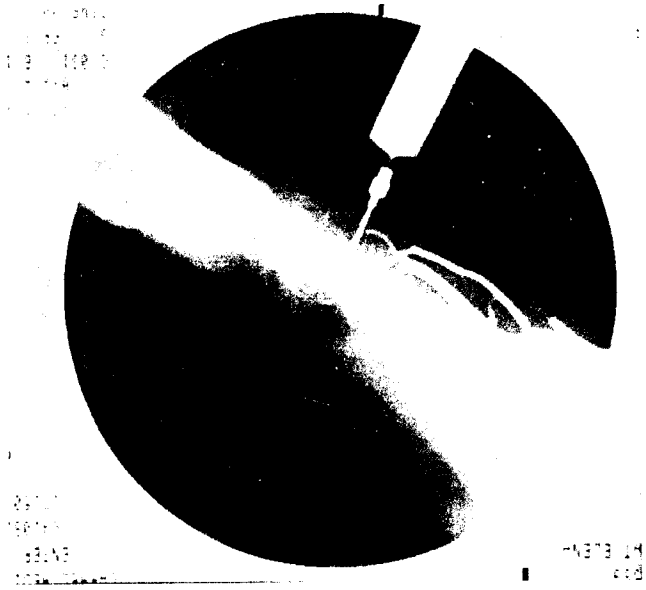

FIG 6. Osteoclysis (intraosseal infusion) of lidocaine 0.5% for regional anesthesia in the distal radial methaphysis of a 65-year-old female, enhanced with contrast material, before an open reduction for a fractured radius.

clear-biological-chemical warfare attack, where medical and paramedical personnel wear gas masks and protective clothing, the task of inserting an iv canula becomes extremely difficult. It has been shown that the insertion of an iv canula takes at least 10 minutes or more in 24% of emergencies, and in 6% of cases in children, no vascular access was established.[12,33] Insertion of a central venous line (internal jugular or subclavian) and peripheral venous lines by surgical "cut-down" technique caused complications in 10 to 15% of cases studied and was associated with multiple potentially fatal iatrogenic complications.[34–36]

Only certain medical personnel such as anesthesiologists, emergency department intensive care unit physicians, and well trained paramedics have high success rates in central vein access as an emergency procedure. Unnecessary suffering and high mortality may be avoided by using the io route for vascular access shortly after a more conservative approach has failed. Establishment of fast and secure vascular access can be obtained by using the BIG technique.

The manual insertion of a trocar needle into the bone is a safe and effective method of establishing vascular access, but with currently available devices, it has a relatively high number of failures, especially in adult patients.[23] We have shown that this can be improved by using an automatic device that allows a fast and precise insertion of a trocar needle to a predetermined depth, without further leakage of fluids around the insertion site. The pain associated with penetration of the needle in conscious patients is considerably reduced by a good local anesthesia infiltration of the skin and periosteum, and by the high speed of insertion using this device. Pain in most of our cases was related to the infusion of fluid under pressure in the conscious patient, lasting for approximately 1 to 2 minutes. As mentioned earlier, discomfort may be reduced by withdrawing bone marrow and by infusing 1% lidocaine.

Complications previously reported with IOI include bone infections and compartment syndrome.[4,20,21,28,37] However, these were mainly related to the length of time the infusion was left in place and to poor technique of needle insertion with subsequent leakage of fluid out of the bone into the surrounding tissues. In more than 4,000 cases reviewed, 0.6% had osteomyelitis, compared with 3.7% of infections related to iv infusions.[19] Defects in bone growth after infusions were not demonstrated in an animal model.[38,39] Bending of the needle and trocar have also been reported.[23] Most of the above complications can be avoided when a suitable device is correctly used by trained personnel, even in relatively hard spongeous bone in adults.[10,24,25,40–44]

In summary, the IOI device and technique described in this study offers a rapid and safe alternative method for accessing the vascular system for administration of fluids, medications, and blood products in elective and emergency situations in the adult patient. We feel that many lives could be saved in mass casualties if medical and paramedical staff were familiar and well trained with the use of the IOI technique. When the minimal risks of this technique are compared with the benefits, it becomes evident that the bone marrow–intraosseous route is safer, easier, and faster than the central venous cannulation or the classical "cut-down" venosection. Therefore, the use of the IOI is strongly recommended in hospital and prehospital emergency situations when an instant vascular access is imperative.

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