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Intraosseous Infusion Devices: A Comparison for Potential Use in Special Operations

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Objective: **To determine which intraosseous (IO) devices were easy to learn to use, easy to use once the skill was obtained, and appropriate for the Special Operations environment.**

Methods: **Thirty-one Navy SEAL corpsmen, Air Force pararescuemen, Army Special Forces, and Ranger medics, in a prospective, randomly assigned, cross-over study, tested four commercially available, Food and Drug Administration-cleared IO devices. The systems included the injection models First Access for Shock and Trauma (FAST, Pyng Medical) and Bone Injection Gun (Wais Medical, Kress USA Corporation) and the hand-driven threaded-needle SurFast (Cook Critical Care) and straight-needle Jamshidi needle (Baxter) models. The Special Operations medical care providers received a lecture regarding IO use, viewed videotapes of the injection models, and practiced with demonstration units in the classroom. Each participant then entered the cadaver lab where all four of the IO devices were placed in randomly assigned order. A poststudy questionnaire was then completed. The FAST was placed in the sternum, whereas the other units were placed in either medial proximal or distal medial tibia. Each participant was assessed for time, number of attempts, and success. The presence of marrow, extravasation, quality of flow, and security of needle were evaluated in combination to help determine success.**

Results: **All four devices were believed to be easy to learn as well as easy to place. FAST was successful in 29 of 30 insertions (94%) with a placement time of 114 ± 36 (mean ± SD) seconds. The Bone Injection Gun was similarly successful (29 of 31 insertions, 94%) with a mean placement time of 70 ± 33 seconds. This time was statistically significantly faster ($p < 0.05$) than that with FAST, but not with the other devices. Thirty of 31 SurFast placements (97%) were successful, on average taking 88 ± 33 seconds to place. The Jamshidi needle also had 30 of 31 successful placements (97%) at an average 90 ± 59 seconds. No one device was rated by the participants as significantly better than the others; however, the Bone Injection Gun did have 65% of participants rate it as first or second (closest was Jamshidi needle at 52%).**

Conclusion: **These IO devices were easy to teach and learn as well as easy to use. Insertion times compared favorably with peripheral intravenous catheter placement in the face of hemorrhage. All four devices can be appropriately used in the Special Operations environment and are reasonable alternatives when intravenous access cannot be gained. Although no device was rated higher than the others, particular features are desirable (low weight/size, simplicity, reusability, secure, clean, well protected).**

Key Words: **Intraosseous, Infusion, Trauma, Special Operations, FAST, BIG, SurFast, Jamshidi needle.**

Intravenous (i.v.) catheter placement remains the gold standard for vascular access and should not be replaced. However, delays and difficulties in establishing intravenous access do occur in the prehospital setting. Catheter placement may prove difficult for even the most skilled, especially in hemodynamically unstable trauma patients during air or ground transport. The Special Operations far forward environment is no exception. In fact, this adverse environmental setting makes obtaining i.v. access possibly more difficult where operations occur in the dark under significant amounts of stress and potentially involve nuclear/biological/chemical protection.

In situations such as shock, for which catheter placement for administration of fluids or medications may be extremely difficult or even impossible secondary to collapsed veins, intraosseous (IO) infusion may provide an alternative route of vascular access. The intramedullary space, where a placed IO needle sits, is highly vascular. This space provides a direct conduit to the systemic circulation that remains open even in the presence of shock. Although the literature does not compare IO insertion time with other i.v. alternatives such as venous cutdown and central line placement, most would agree that cutdown and central placement require significant time, as well as expertise.

Several animal and human studies show IO infusion to be a safe, as well as effective, means of administering medications and fluids.[1–9] Multiple medications, crystalloids, colloids, and blood products are reported to have been infused by means of the IO route.[8,10–13] Systemic response times of drugs to IO injection compare similarly with central and peripheral venous administration and seem faster than endotracheal administration.[13–17]

IO use is well established in the pediatric community. The American Heart Association, the American Academy of Pe-

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diatrics, and the American College of Surgeons recommend the IO route in children when peripheral venous access is not immediately possible.[18] Although the basic principles and theory behind IO use in adults and pediatrics is the same, use of IO as a possible vascular route in the adult population has been investigated only recently.[2,3,5,9]

Use of the IO route in prehospital adults may also provide the best secondary vascular route when a peripheral i.v. cannot be established. Indications for prehospital IO access include failed peripheral i.v. in adult patients who require emergency vascular access, situations for which a central line or cutdown are not reasonable options. This may be especially true in tactical medicine.

No prior studies have compared the newer First Access for Shock and Trauma (FAST) and Bone Injection Gun (BIG) intraosseous models with standard hand-driven SurFast (SF) and straight-needle Jamshidi needles (JN) or looked at Special Operations medical care provider ability to use IO devices. It was our intent to determine which IO devices they could easily learn, which IO devices they could easily use, and to discover whether these Navy SEAL corpsmen, Army Special Forces and Ranger medics, and Air Force pararescuemen believed any of the units were appropriate for the Special Operations environment.

MATERIALS AND METHODS

Institutional Review Board approval was obtained from the Uniformed Services University of Health Sciences (USUHS, Bethesda, Md). Thirty-one Special Operations corpsmen, medics, and pararescuemen, attending Operational Emergency Medical Skills (OEMS) courses (USUHS) participated in the study.

Four FDA-approved models were believed to have potential for the Special Operations environment. The devices tested were FAST (Pyng Medical Corporation, Vancouver, British Columbia, Canada), BIG (Wais Med, Kress USA Corporation, Kansas City, Mo), SF (Cook Critical Care, Bloomington, Ind), and JN (Baxter Allegiance, McGaw Park, Ill).

The FAST (Fig. 1) comes as a complete package with intraosseous equipment, alcohol, iodine, and protective and securing dressing, as well as remover. This unit is intended for sternal use only. After cleaning the sternum with iodine and alcohol, an adhesive target patch is placed over the manubrium, midline, and approximately 1.5 cm below the sternal notch. The introducer is placed in the target zone. The unit's introducer handle contains a "bone cluster" of needles forming a circle (Fig. 2), which functions to sense the cortex of the sternum. Continuing pressure on the handle releases an inner needle upon which a plastic infusion tube with a small metal tip (bone portal) is loaded. This central needle advances exactly 5 mm beyond the circular cluster of needles which stop at the cortex. The metal tip of the plastic infusion tube is perfectly positioned at the inner cortex, the medullary space border (Fig. 3). Withdrawal of the handle now leaves only the plastic infusion tube protruding from the insertion site. Marrow aspiration and rapid flow through i.v. tubing connected to a fluid source help verify position. A plastic dome attaches to Velcro upon the initially placed target patch, securing and dressing the unit. Removal of the infusion tube requires the use of an included threaded tip remover (Fig. 1). The tube can also be removed with direct pulling; however, the metal tip

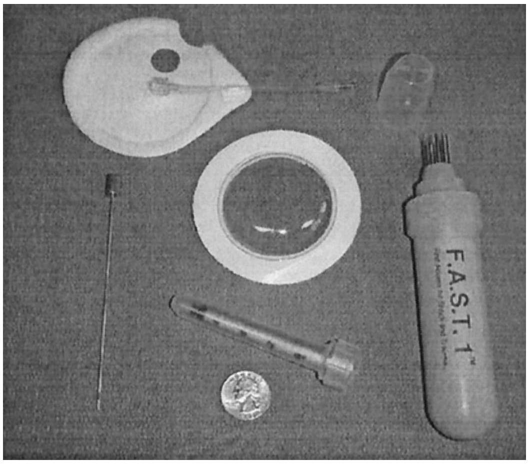

FIG 1. **The FAST package opened. Individual components are seen. The infusion tube removal device lies along the left-hand side of the photo. Toward the top, the adhesive-backed target patch with i.v. tubing strain relief and circular Velcro are seen. The protective plastic dome (center) attaches onto the target patch once the infusion tube has been inserted. An aspirating 1-mL syringe is included. The FAST introducer handle appears on the far right.**

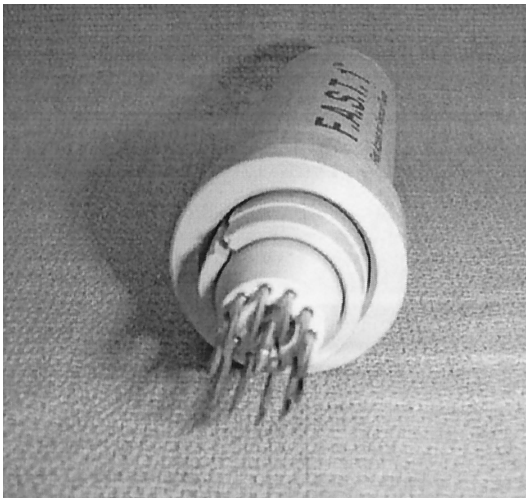

FIG 2. **The FAST bone probe cluster is in a circular pattern. The infusion tube is mounted on the center needle.**

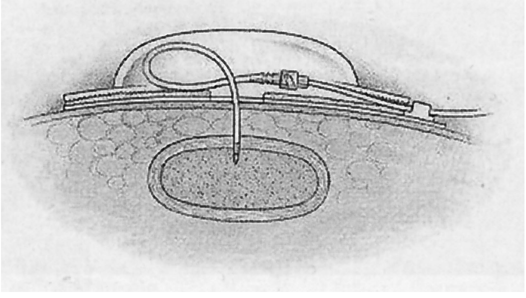

FIG 3. **The FAST infusion tube positioned with the metal tip (bone portal) at the cortex-medullary border. Flexible tubing exits subcutaneous tissue, protected, secured, and visualized through the clear plastic dome (with permission from Pyng Medical).**

FIG 4. **The BIG. The slotted safety pin seen on the far end may be used to secure the IO needle after placement. Centimeter markings are seen below the flange (the flange is next to the arrow tip). Twisting the fluted end sets a centimeter level, allowing control of penetration depth.**

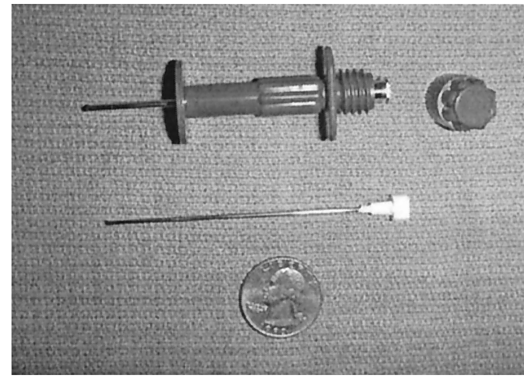

FIG 6. **The JN with the top cap and stylet removed. An inserted JN IO needle protrudes the distance seen from the flange on the left to the metal top (seen on the right above the threads).**

may then have to be extracted after a small incision and exploration.

The FAST is designed for sternal placement. The other IO devices are not used in the sternum, but may be placed at multiple different sites. Potential options include the proximal and distal tibia, femur, iliac crest, humerus, radius, and clavicle. The BIG (Fig. 4) incorporates a loaded spring to inject its needle. The desired depth of injection is adjusted, by screwing/unscrewing the far end, and the safety pin removed from the opposite end. Palmar force on the back of the unit, combined with pulling on flanges with the middle and ring fingers (directions on package), results in firing of the gun. Aspiration, followed by flushing with the same syringe, and flow through i.v. tubing help confirm placement. The slotted safety pin is slid onto the needle to maintain stability. The site is then dressed in a manner determined by the care provider. The needle is removed with small clamps that are rotated back and forth.

The SF (Fig. 5) kit consists of a handle, threaded SF needle, and miniature scalpel. After preparation of the insertion site, a skin nick is created with the scalpel. Back and forth motions obtain purchase for the needle, which is then advanced with clockwise rotation and pressure on the handle. The company does not recommend aspiration, but flushing with a fluid filled syringe and observation of flow through i.v. tubing help confirm correct placement. The site is dressed according to the care provider. Although the needle is securely placed, counterclockwise rotation allows easy removal.

The JN (Fig. 6) originated as a bone marrow biopsy needle. Those with previous exposure to IO are most likely to have seen the JN. Also known as the Illinois sternal bone marrow needle (although not recommended for sternal placement in the emergency setting), depth of insertion may be adjusted by screwing/unscrewing the far end. The unit advances as back and forth rotation and pressure are applied. A loss of resistance is felt as the needle “pops” into the intramedullary space. The top end is unscrewed, and the stylet removed. Flushing with a fluid filled syringe follows aspiration for detection of bone marrow. The i.v. tubing is then connected and flow is observed. As with the SF and BIG, the site is dressed per the person placing the JN. A correctly placed JN protrudes at least 2 inches from the skin when in position. The device is removed with a twisting, pulling motion.

Each of the four devices was weighed and measured. Table 1 contains package weights as well as some of the individual component weights. Measurements of the package include maximum dimensions in each direction with the packaging compressed as much as tolerated. Weights and volumes of components required to make two treatments are also included.

The OEMS students received a 60-minute general lecture on IO devices, followed by instructional videos on FAST and BIG. They were then allowed a hands-on session with FAST and BIG demo units, as well as SF and JN devices.

The Special Operations medical care providers were brought to the human cadaver laboratory. Each corpsman or medic tested all four systems in random order. FAST units were placed in the sternum, whereas the others were placed in either the proximal medial tibia (approximately 1–2 cm medial and 1 cm proximal to the tibial tuberosity) or the distal medial tibia (approximately 1–2 cm proximal to the medial malleolus). Time of placement was recorded starting with preparation of the insertion site and ending when the Special Operator believed that the unit had been successfully placed. Time to secure the device was not included. We chose to focus on insertion time only, rather than including time to secure the device, because only one device (FAST) has a

FIG 5. **The SF. The kit components, instructions, small scalpel, SF threaded IO needle and driving handle are shown.**

TABLE 1. Weight and dimensions[a]

Parameter	FAST	BIG	SF	JN
Weight (g)				
Unit in pack	162	99	88	16
Out of box		81		
Package w/small handle			40	
Two units	322	198	92 big handle 44 small handle	32
Dimensions (L × W × H) (inches)				
Complete pack	6.5 × 3.5 × 1.4 (soft)	6.5 × 2.8 × 1.5 (hard)	4 × 4 × 1.8 (hard)	3.5 × 1.5 × 0.8 (soft)
Unit alone	6.3 × 1.5 diam	5 × 1.8 × 1		3.5 × 1 × 0.8
Needle alone			1.5 × 0.4 × 0.3	
Scalpel alone			3.4 × 0.8 × 0.4	
Handle-small			1.4 diam × 0.7	
Handle-large			2.1 diam × 1.8	
Two units increase in volume	Doubled	Doubled	No change	Doubled

[a] Weight is initially described as number of grams for complete package as it comes from the manufacturer. The BIG weight from row 2 is reported after the outer box has been removed, with the inner sterile packaging still present. The SF weight reported in row 3 reflects a smaller handle (large handle removed). The "Two units" row involves the total weight carried for two possible treatments. For FAST, BIG, and JN, the package weights are simply doubled. For SF, the weight of an extra needle (3.8 g) is added. Space taken up in a rucksack is not changed when carrying two SF needles, whereas it doubles with the other units. Dimensions reflect maximum values when package is compressed. Packs were either hard or soft plastic. The manufacturers of FAST, BIG, and SF have indicated willingness to change packaging if desired. "Diam" refers to diameter dimension. L × W × H indicates dimensions for length × width × height.

routine way in which it is secured. The other three may be secured in various ways, which would lead to large variance in times, with no consistent assessment. Only successful placements were used to calculate average insertion times.

Success was determined by using aspiration of bone marrow, flow of fluid with flushing of syringe used for aspiration, flow of crystalloid under pressure (300 mm Hg, inflatable infuser bag), and security of the needle after placement. Presence of bone marrow was helpful; however, absence of bone marrow upon aspiration did not equal failure. One manufacturer (Cook) does not recommend aspiration with its SF. Flow was noted within the i.v. tubing drip chamber as good (fast flow), fair (continuous but slow), and poor (minimal flow). Presence of extravasation (leakage of methylene blue-dyed lactated Ringer's solution or normal saline) was recorded. Security of the needle was rated as very secure (no play), moderate (some play), and insecure (no purchase/easily dislodged). The above factors have been used to confirm placement in other studies.[3,5,7]

The Special Operators participating in the study then completed a questionnaire dealing with ease of learning, ease of use, and appropriateness of the device for their work environment. Advantages and disadvantages were listed, and the devices were ranked.

Time of placement is reported as mean ± standard deviation (SD). Friedman's repeated measures analysis of variance on ranks was used to look for evidence of significant differences in time of placement and successfulness of placement among the devices. This analysis was followed by an all pairwise multiple comparison procedure (Tukey's test) to determine statistical significance if differences were suggested by the analysis of variance.

RESULTS

Weights and dimensions of the IO devices are reported in Table 1. Results for successful placements of the four intraosseous devices are shown in Table 2. Similar success

TABLE 2. Results

Device	Time for Successful Placement Mean ± SD (s)	Success Percentage (Success/Attempts)	Security/Flow/Extravasation (Successful Placements)
FAST	114[a] ± 36	94 (29/31)	All rated very secure (29/29) Good flow in all (29/29) Some extravasation (2/29)
BIG	70 ± 33	94 (29/31)	Rated very secure (28/29, 1 moderate) Good flow (27/29, 1 fair and 1 poor) Some extravasation (2/29)
SF	88 ± 33	97 (30/31)	Rated very secure (28/30, 2 moderate) Good flow (27/30, 3 fair) Highest extravasation rate (8/30, 4 minimal)
JN	90 ± 59	97 (30/31)	All rated very secure (30/30) Slow flow noted (7/30), good in 23 Some extravasation (2/30)

[a] Significantly slower than the other devices ($p < 0.05$).

TABLE 3. **Preference ranking for the IO devices[a]**

Rank	FAST (%)	BIG (%)	SF (%)	JN (%)
1	32	19	19	32
2	13	45	23	19
3	29	19	29	19
4	26	16	29	29

[a] Each study participant ranked the devices in order of preference. The results are presented as percentages (n = 31). Note that BIG received approximately two thirds of its votes in either first or second place. Totals for BIG and JN are 99% because of rounding.

rates were seen among the four devices. However, BIG, SF, and JN were inserted significantly more quickly than FAST ($p < 0.05$).

Successfulness did not seem to improve from the first device tested to the last device. No failures occurred with any of the randomly assigned devices on the first attempt. Two failures occurred with the second device tested (one JN and one BIG). Three failures occurred with the third device used (one FAST, one BIG, one SF). One failure occurred with the last (fourth) device tested (one FAST).

Two failures occurred in 31 attempts at FAST placement. Both of these seemed to be caused by lack of continuous increasing pressure on the FAST unit as it is compressed over the sternal insertion site. Two failures were experienced in the 31 BIG placement attempts. In one instance, the operator failed to keep pressure over the top of the BIG, by using only his thumb, rather than the palm of the hand. In this case, the BIG unit moved backward rather than injecting the needle forward. The second failure with a BIG occurred after successful initial insertion. However, because the stylet within the needle was stuck, the operator ended up pulling out the needle while attempting to forcefully remove the stylet. One failure was noted in 31 attempts at placing a SF. This failure was caused by an error in identifying proper landmarks. A single failure was also observed in the 31 JN placements, which occurred because of a bent needle.

The questionnaire established that the Special Operations medics/corpsmen/pararescuemen believed that all four devices were easy to learn as well as easy to place. They also rank ordered the four IO devices such that there had to be a first, second, third, and fourth choice made by each evaluating person (Table 3). Averages rankings were calculated for each device (BIG, 2.3; JN, 2.4; FAST, 2.5; SF, 2.7), but analysis of variance showed no significant difference among the rankings. Note that BIG received almost two-thirds of its ranks as either first or second place.

DISCUSSION

In the present study, IO devices were largely successful. The failures that did occur in our study were a result of an error in landmarks and a bent needle, the most common problems seen in a prior study.[3] We also saw additional failures caused by lack of constant pressure on the newer FAST and BIG models. Clear instructions should prevent most errors. These devices should not be used without prior formal "hands-on" teaching. Although minimal deterioration in skill has been reported,[3] occasional refresher training will probably be necessary to avoid errors seen in this study. This training would not be extensive.

Measurement of time required to place the IO devices was recorded so that we might determine whether any of the devices were clinically significantly slower than the others. We were also interested in a general assessment of placement times that could be compared relative to peripheral i.v. placement, cutdown, or central line placement. Although there were statistically significant differences in placement times for the various devices, all the devices had acceptable times when compared with attempting to obtain peripheral i.v. access, especially in the face of shock. We believe that these times (114 seconds or less) compare favorably with cutdown and central line procedures.

Although placement time is a consideration, site of insertion is also an important factor in the military setting. Approximately two-thirds of battlefield casualties have extremity wounds of some type,[18] which could prohibit IO insertion of certain devices in that injured extremity. However, damage would have to occur to all four extremities to prevent use of BIG, SF, or JN. Although blunt trauma is less common in the military than in the civilian setting, it may still occur, thus, potentially preventing FAST placement if the sternum is involved. Trauma or recent prior attempts of IO at a particular location should preclude insertion at that site. Although some extravasation may be seen even in correctly placed IO needles (occurring in 12% of placements in the study by Glaeser et al.,[3] large amounts of extravasation or even small amounts of hemodynamic medications should prompt the medic to use another insertion site. For our study, cadavers were not dressed in battle-dress uniforms, an option for which expense as well as required effort would have been significant. This would have added additional time for exposure with all the devices, but would not have significantly altered the conclusions of this study.

That all four devices were is easy to learn to use and no one ranked significantly better than the others is evident. However, particular features make the IO devices more or less preferable. The FAST's plastic infusion tube, Velcro patch, and plastic dome cover make it the most secure and easiest dressed of the units tested. In an environment where the casualty may be carried over the shoulder or in make-shift stretchers, for which possible dislodgment is a significant concern, the FAST seems to have the best design. This system is probably more secure than a standard peripheral i.v. Although some have concerns about the insertion site interfering with other procedures, cricothyrotomy and cardiopulmonary resuscitation can be performed around the protective dome. Local anesthetics may be injected at the site of insertion with any of the models to minimize pain in awake patients. Disadvantages of the FAST relate to its size and weight. This unit was the largest and heaviest of those tested. Of note, Pyng Medical is working on improving its current model. A prototype has been developed that significantly reduces size and weight (reportedly the cartridge will be 4.4 inches long × 0.6 inches wide and weigh 110 g, additional needles, for multiple treatments, weigh 10 g). With existing FAST units, only one attempt can be made per unit. Further attempts or the need for access in more than one casualty require the medic/corpsman to carry more than one FAST. The need to treat two times requires carrying double the weight and volume (see Table 1). Cost is approximately $100.

The BIG functions quickly and easily. Depth can be adjusted for insertion at multiple different sites. Placement is secure, although the IO needle does protrude slightly. The safety pin for the BIG doubles as a security measure, but additional dressing is necessary. Rapid insertion of the needle is an advantage. This unit did have the best average ranking and most first and second place votes, although this ranking was not statistically significant. Like the FAST, only one attempt can be made per unit. Additional BIGs must be carried if multiple attempts or casualties are anticipated. Like the FAST, carrying two BIG devices, doubles weight and volume. Accidental injection into the medic/corpsman's hand is a concern because the device can be held backward. The possibility of losing a needle from the gun (seen in this study) is worrisome; however, as a result of this study, the company has reduced the inside diameter of the spring retainer which holds the needle, thus, improving holding power. Cost is approximately $85.

The SF represents a simple, lightweight design that allows more than one attempt with the same needle in a single patient. In addition, one driving handle may be used with multiple SF needles without significantly increasing weight or space. Therefore, multiple treatments can take place carrying equal or less weight and volume than a single unit of the other IO devices. The SF can be placed in many different sites. Like JN and BIG, the SF needle does protrude, although to less of a degree than these others. La Spada et al. were not able to show less extravasation with threaded needle units like SF (we saw a trend toward more extravasation), although it did seem to have more easily controlled penetration depth and less resistance to dislodgment than other hand-driven systems.[19] Disadvantage relates to the need for significant pressure for insertion and use of a second hand for stabilization. Cost is approximately $40.

The JN is very simple and the unit most likely to have been seen before the study. Simplicity results in fairly rapid placement times. Penetration depth is adjustable for controlled placement at multiple different sites. This device, like the SF, allows more than one attempt with the same JN in a single patient. Multiple casualties will require carrying additional complete units, although these are relatively light and small. Concerns center around the high profile of the needle, which remains after insertion. The JN protrudes at least 2 inches after placement, making dislodgment likely in the face of rapid movement over rugged terrain in less than ideal circumstances. Cost is approximately $20.

CONCLUSIONS

All IO devices tested were easy to learn and use. It was the impression of the authors that instructing others in the placement of the four tested devices was not difficult. Special Operations corpsmen, medics, and pararescuemen can appropriately use the four devices. After completing a relatively simple training session, we believe these individuals could use any of the four test devices. If weight and volume are not of significant concern, FAST seems to offer the appropriate option, because of a complete package and excellent protection of insertion site. With new modifications, the size issue may not be as much of a concern. The BIG was quick and very simple to use. Design improvements seen as a result of this study make it a viable option. SF requires significant force and a little more care during insertion than the first two devices (FAST, BIG), but does allow for the treatment of the most casualties with the least amount of weight and space taken in the medical bag. When size and weight are significant concerns, this may offer the best choice at present. The JN is lightweight and simple to use; however, concern centers around the high-profile, less secure nature of the device.

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