A Magnetic Resonance Imaging Study to Define Optimal Needle Length for Humeral Head IO Devices

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ABSTRACT

Introduction: Intraosseous (IO) devices have gained popularity because of TCCC. The ability to gain access to the vascular system when intra venous access is not possible, and techniques such as central lines or cut-downs are beyond the scope of battlefield providers and tactically not feasible, has lead to the increased use of IO access. Since tibias are often not available sites in blast injury patients, the sternum was often used. Recently the humeral head has gained popularity because of ease of access and placement. The optimal needle length has not been defined or studied. **Methods and Materials:** Fifty consecutive shoulder MRIs among 18–40 year old patients were reviewed. Distances from the skin surface to the cortex from anterior and lateral trajectories were simulated and measured. Two different lateral trajectories were studied described as lateral minimum and lateral maximum trajectories, correlating with seemingly less and greater soft tissue. The cortical thickness was also recorded. Mean values and ranges for the measurements were determined. **Results:** The anterior trajectory represented the shortest distance. Mean anterior, mean lateral minimum and mean lateral maximum distances were 2.3, 3.0 and 4.7cm with corresponding ranges of 1.1–4.1, 1.6–5.7 and 2.8–7.4cm respectively. The cortical thickness was 4mm in all cases. **Conclusions:** Although this information was gathered amongst civilians, and many military members may have more soft tissue, these results indicate that needle length generally in the 40–50mm range should be used via the anterior approach. Use of a standard 25mm needle often used in the tibia would be inadequate in over half the cases, and may result in undue tissue compression or distortion.

Introduction

Access to the circulation is often required to treat critical medical and traumatically injured patients. Intraosseous (IO) infusion is one method for accessing the circulation through the medullary space of the bone in order to administer fluids, blood, and pharmaceuticals. Drinker first described the theoretical use of IO infusion in 1922.[1] This method of fluid administration gained popularity around the year 1940 and was used during World War II.[2] With the advent of plastic cannulas for intravenous infusion (IV) and the lack of formal emergency medical services (EMS) systems, IO use fell out of favor after the war.

Recent improvements in IO design have led to the reemergence of this valuable tool for the medical provider. Newer devices using spring-loaded needles and drills have allowed easier access to the medullary space in adults who have thickened and harder bone cortex. Due to the ease of these new devices and multiple studies confirming that IO access is safe, simple, and effective, their use in adult resuscitation has flourished.[3-5] Recent clinical practice guidelines have emphasized IO use and these recommendations have been promoted through the European Resuscitation Council, the Advanced Cardiac Life Support, the Advanced Trauma Life Support, and the Pediatric Advanced Life Support courses.[6-9]

The military, through the Tactical Combat Casualty Care (TCCC) guidelines, has championed the use of IO devices to gain access to the circulatory system in situations where IV access is difficult to obtain.[10] On the battlefield, hemorrhagic shock is an absolute indication for fluid resuscitation, but that same condition often makes IV access difficult to obtain. Because of these limitations, in 2003 the TCCC guidelines were updated to include the use of IO access.[11] The Committee on TCCC does not recommend a particular IO device; however, it does note a preference for the sternal site of insertion while specifically mentioning large bone (tibia and humerus) insertion as an important secondary site for backup. Today, many military units also utilize devices for tibial and humeral IO access.

The large percentage (approximately 50%) of combat injuries are due to IED explosions, and has resulted in the loss of many lower extremities and the inability to place tibial IOs. This has lead to the need to use other sites, which helped lead to the popularity of the upper sternum. More recently we have seen the humeral head become increasingly used.

This is illustrated by the mission experiences of two separately located USAF Pararescumen in Afghanistan. From 1 September through 24 November 2011, they flew missions with 387 patient contacts. They picked up ten patients who already had IO's, six humeral head and four sternal; and placed thirteen IO's comprised of eleven humeral head and two tibial (both pediatric patients) placements (internal data 103RQS). Thus, the trend is towards the use of humeral head placement over sternal.

Both the tibial and humeral head sites can be associated with technical challenges. One study showed a first pass success rate for the tibia and humeral head respectively in out of hospital cardiac arrest of 89.7% vs. 60%.[12] Similarly, the Armed Forces Institute of Pathology (AFIP) recently reported failed humeral head IO insertions during resuscitation in patients who subsequently died.[13] Note that the AFIP only reports on post mortem examinations; therefore the denominator for the same time period is not known. The AFIP reported data for 24 humeral IO insertions, 21 used the 45mm needle requiring an electrically powered driver to insert, and 3 used the 25mm needles, which can be inserted manually. Successfully entering the medullary space occurred in 16 (76%) patients using the 45mm needle, and 0 with the 25mm needle.

Other data in theater for sites of IO insertion are not readily attainable because the Joint Theater Trauma Registry records if an IO line was placed and does not specify the site.

Difficulties with humeral head insertion can be related to an increased surface to bone distance in muscular patients with thicker deltoids, difficulty in identifying correct landmarks in very muscular patients, and the glancing of the needle tangentially off the surface of the spherical humeral head if it is not placed perpendicularly. The depth from skin surface to the marrow cavity is greater over the humeral insertion site than the tibia or sternal access points. The most popular IO device for gaining access to the tibia and humerus in the field is the EZ-IO® (Vidacare, Shavano Park, TX). Most combat medics carry only one needle size in an attempt to limit the weight and size of the medical equipment carried in their aid bag. That needle is typically the 25mm needle (blue hub) since it can be inserted using a manual drilling motion and does not require the combat medic to pack the battery powered driver. One explanation for the AFIP data described above is that the distance needed to access the medullary cavity in the humerus exceeds 25mm causing failed or easily dislodged IO access. Detailed information describing the distance from skin surface to the medullary space is lacking. As the use of humeral head IO access increases, reliable data affecting the technical aspects of placement is needed.

We undertook this study to determine the average distance and range from the skin surface to the medullary cavity of the humeral head using multiple trajectories in an attempt to ascertain if the commonly carried 25mm needle is long enough to access this site.

Methods

Retrospective identification of 50 consecutive 18–40 year-old patients between undergoing non-contrast magnetic resonance imaging (MRI) of the shoulder for shoulder pain was performed utilizing a search function of the Advanced Data Systems Radiology Information Systems database in a single civilian radiology practice. Selected patients ranged in age from 18 through 40 years. Scans were unarchived and images reviewed for quality. Scans with excessive patient motion or image noise were rejected. Fifty patient studies were subsequently selected.

Imaging was performed on one of the following MRI systems in the standard manufacturer provided shoulder coil:

General Electric Horizon LX 1.5T (software version 9.1) and General Electric Excite 1.5T (software version 12.0), General Electric Healthcare Systems, Waukesha, WI.

Hitachi Altair 0.7T (software version 601711), Hitachi Medical Systems America, Inc. Twinsburg, OH.

Siemens Symphony Maestro 1.5T (software version VA25). Siemens Medical Solutions USA, Inc. Malvern, PA.

Images were reviewed on a DR Systems PACS (current system version July 2011) utilizing a standard MRI hanging protocol. Four distance measurements were obtained per patient utilizing DR Systems standard PACS tools. Cortex thickness, anterior skin surface to cortex, lateral skin surface to cortex and posterolateral skin surface to cortex. Measurements were obtained from an axial T2 fat sequence at the level of the coracoid process as illustrated in Figure 1.

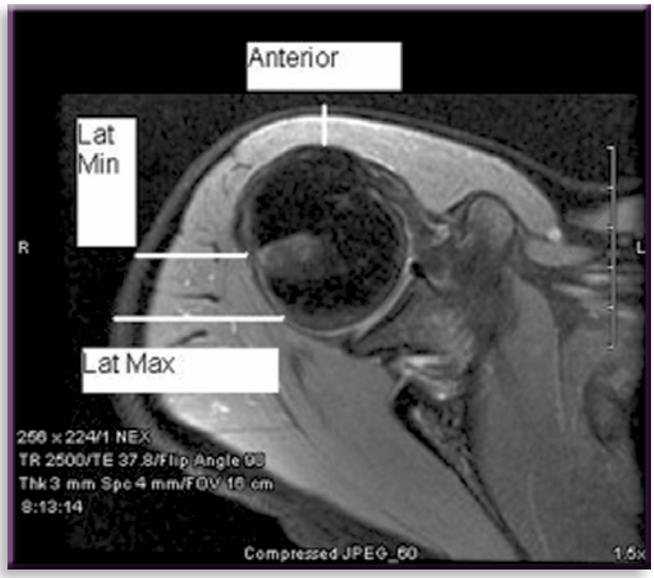
Results

There were 17 female and 33 male patients. The mean age was 32 years with a range of 1945.

The mean distances and ranges (in cm) from the skin surface to the bone surface for the different techniques were as follows:

Technique	Mean	Range
Anterior	2.3	1.1–4.1
Lateral minimum	3.0	1.6–5.7
Lateral maximum	4.7	2.8–7.4

Figure 1 *Axial T2 fat sequence illustrating how the measurements were taken.*



The details are shown in Table 1.

The thickness of the cortex was 4mm in every instance. Thus, the distances from the skin surface to the medullary space were 4mm plus the distances above. For example, the mean anterior distance from the skin surface to the intramedullary canal was 2.7cm and the range was 1.5 to 4.5cm.

Discussion

One of the most commonly used IO devices in military medicine is the EZ-IO family of products. The EZ-IO needles are available in lengths of 7.5mm (green hub), 15mm (pink hub), 25mm (blue hub), and 45mm (yellow hub). The instructional material from the manufacture indicates that the 25mm needle is designed for any patient weighing more than 39kg. It has been our experience that combat medics often elect to carry only the 25mm EZ-IO needle set for two reasons. First is that the 25mm needle is the only currently available length, which comes pre-packaged with a device that allows manual insertion of the device without using the EZ-IO battery powered driver. This allows the medic to save space and weight in his aid bag. Second, the literature from the manufacturer seems to indicate that the 25mm needle should work with the majority of the patients the medic is likely to encounter in the field, as it is marketed for any patient greater than 39kg.[14]

The EZ-IO devices are FDA approved for use in the distal tibia, proximal tibia, and proximal humerus. In training scenarios the proximal tibial site is often chosen for insertion of the device because of ease of access, and anatomical landmarks that are easy to learn and find on

Table 1 *Demographics and measured distances (Ant = anterior, lat min = lateral minimum, lat max = lateral maximum)*

Number	Age	Gender	Ant	Lat min	Lat max
1	37	F	2.1	3.1	4.5
2	20	F	1.1	1.6	3.6
3	31	F	1.3	2.2	3.7
4	35	F	2.7	2.9	3.7
5	22	M	1.8	2.6	5.0
6	41	M	1.8	2.2	3.8
7	30	M	1.4	3.2	5.5
8	22	M	2.0	3.5	5.8
9	19	M	2.3	3.3	4.8
10	19	M	1.2	2.8	4.1
11	30	M	2.5	5.7	6.8
12	21	M	2.7	4.1	5.5
13	20	F	2.1	3.8	5.5
14	33	M	1.9	1.8	2.8
15	45	M	1.6	3.3	4.6
16	31	F	2.6	4.8	7.4
17	35	M	1.6	2.6	3.5
18	28	F	3.2	4.4	5.4
19	31	F	3.6	4.0	5.9
20	44	M	2.4	3.0	5.4
21	43	M	1.5	2.3	4.4
22	30	M	2.8	3.9	6.2
23	28	M	1.9	2.3	3.8
24	41	M	2.6	4.0	6.3
25	42	M	2.5	2.2	3.9
26	19	M	2.0	3.1	5.2
27	22	M	2.3	3.7	4.6
28	36	M	2.1	1.9	4.0
29	21	F	1.4	2.6	4,3
30	30	M	1.3	3.2	4.8
31	24	M	3.6	2.1	4.2
32	36	F	2.6	2.4	3.1
33	45	M	1.7	2.3	4.9
34	19	M	2.6	2.8	5.1
35	40	M	2.1	2.6	4.4
36	31	M	4.1	4.4	5.8
37	37	F	2.6	3.2	4.6
38	44	F	2.3	3.0	4.2
39	44	M	3.2	3.4	5.8
40	40	F	1.1	2.2	3.3
41	33	M	3.9	3.8	6.1
42	39	M	2.6	3.3	4.4
43	31	F	1.5	1.6	2.8
44	31	F	2.4	4.5	6.6
45	45	M	2.5	3.5	5.0
46	45	F	1.3	2.2	3.2
47	44	M	2.7	2.6	5.7
48	20	M	2.8	1.9	3.5
49	32	F	1.7	2.3	4.1
50	42	M	3.0	1.8	3.3

the majority of patients, irrespective of muscularity and body habitus. Experience in the current military conflict has shown that blast injuries from IEDs or other high-energy devices result in the loss or mangling of the lower extremities. As the only other FDA approved site, the proximal humerus is often used when the tibia is not suitable, or when multiple IO access sites are desired, while the sternum is still preferred by others.

In order to reliably enter the marrow the IO needle needs to not only reach the surface of the bone, but also must penetrate the cortex and enter the intramedullary space. The manufacturer of the EZ-IO needles teaches that the method to ensure the needle length is adequate is to insert the needle through the soft tissue until the tip touches the cortex of the bone. Then the needle position at the skin surface is examined. The hub flange should be at least 5mm away from the skin surface, which takes penetration of the cortical thickness in to account. We agree with this based on the thicknesses measured in our study. The EZ-IO needles are marked at 5mm increments to facilitate this measurement. Consideration should be given to changing the recommended protocol to allow for a distance of 10 mm from the hub flange to the skin. This would allow the penetration of the 4mm cortical thickness and subsequent satisfactory seating of the IO device in the intramedullary canal.

There has been some concern that the 25mm needle length is not long enough to reliably enter the marrow space when used in the proximal humerus insertion site. The manufacturer's own web site states that the 45mm needle set, not the 25mm needle, is ideal for the humerus insertion site in patients weighing more than 39kg. This recommendation has been confirmed in the recent autopsy data from Dover AFB Mortuary, which also indicates that the 25mm needle is not long enough for use at the humeral site.[13] The Armed Forces Medical Examiner Service examined a series of 24 EZ-IO humeral insertions during autopsy of patients at Dover AFB Mortuary. Of these insertions, three used the 25mm EZ-IO needle. None of the three were seated in the intramedullary humeral space, one was in a marginal position in the cortical bone, and two were not seated in the humeral bone.

Data from an emergency department study in Singapore indicated that the humeral site was accessed successfully with EZ-IO 25mm needles in 11 of 11 attempts.[15,16] Unfortunately this study did not record the weight, BMI or body habitus of the patients, so its applicability to wounded American or coalition military members who have a different body habitus is uncertain. It is also possible to get the needle to seat in the bone with compression of the soft tissue, but this pressure may result in soft tissue trauma.

Because of limited prior study and conflicting data, we decided to investigate the needle length that would be needed to reliably enter the marrow space at the proximal humerus. We examined MRI data for individuals undergoing imaging for shoulder pain at a non-military hospital system.

The instructions for humeral site selection provided by the EZ-IO manufacturer require that the patient's hand be placed on their abdomen and the elbow adducted completely to the torso.[14] The anterior aspect of the humerus is then palpated proximally until the greater tubercle is felt. The insertion site is described as approximately 1cm proximal to the greater tubercle. This method locates the site of insertion on the anterior to anterior-lateral aspect of the humerus.

In order to account for variation of technique, and to investigate if there is an approach that would optimize the chances of success with a given needle length, we measured the depth to the surface of the bone from the skin surface in three different trajectories. The anterior measurement most closely approximates the location for insertion as described in the manufacturer's instructions. We also measured the minimum and maximum soft tissue thickness from a lateral approach. In order to investigate if the 5mm recommended by the manufacturer was sufficient to penetrate the cortex and reach the marrow we measured the thickness of the cortex. All measurements were obtained from an axial T2 fat sequence at the level of the coracoid process. Table 1 shows the results of our measurements. The cortex was measured to be 4mm in all cases.

Assuming a 4mm cortical thickness, examination of our results shows that only 20 of 50 patients had a skin to bone surface measurement less than 2.1mm. These are the only patients in whom a 25mm needle would be barely long enough to reach the intramedullary space using the anterior approach, and not necessarily allow for free flow of fluid Thus, the skin to cortical surface thickness must be no greater then 2.0 cm to allow full penetration of the 4mm cortex and full penetration by the beveled needle. A 25mm needle would not be long enough to reach the marrow reliably in 30 of 50 patients with an anterior approach without compression and distortion of the soft tissue.

Our data indicates that the 25mm needle cannot be relied upon to reach the marrow consistently when using the anterior humeral approach, and that the 45mm needle should be routinely used. A lateral approach is not recommended because of the increased soft tissue thickness, as well as a greater risk of dislodgement during patient movement from getting hit from the side.

Limitations

Our study has a number of limitations. First, our patient cohorts were civilians who were having imaging studies of their shoulders due to shoulder pain. We did not have data on weight or BMI of our cases and were not able to compare this data to similar parameters for Soldiers, Sailors, Airmen and Marines. It seems likely that the wounded military member is going to have more muscle and soft tissue at the site of humeral IO insertion, which would make the 25mm needle even less appropriate than our study would indicate. Second, measurements were taken retrospectively, and because of this arm position was not controlled for and may not have been in the optimal position for IO insertion as described by the manufacturer. We attempted to control for this by taking measurements in three distinct areas to account for the range of soft tissue thickness, which could be encountered based on the specific approach taken. Third, this study is a retrospective investigation of imaging only, and idealizes the ability to direct a needle placement.

Further studies should be performed taking BMI into account.

Conclusions

The widespread adoption of TCCC as well as increasing use of IO access in civilian pre-hospital care has resulted in increased use of this technique. Wounding patterns in OIF/OEF resulting in the loss of intact tibias have lead to the increased use of humeral head (proximal humerus) IO insertions.

Intraosseous IV access has a long history of use, but has only recently been popularized for adult and pediatric trauma patients in the past ten years because of the adoption TCCC guidelines, as well as adoption in the civilian sector. Recent advances in needles and insertion devices have made IO access quick and easy to reliably establish with minimal training. The EZ-IO system is one of the most widely used of the current IO systems and has been proven on the battle field and in studies to be effective at quickly and reliably establishing IV access. This study supports data collected during autopsy, which indicates that the 25mm EZ-IO intraosseous needle cannot be relied upon to consistently reach the marrow space when inserted at the humeral location. We recommend that the EZ-IO 45mm needle.

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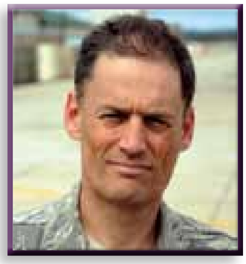

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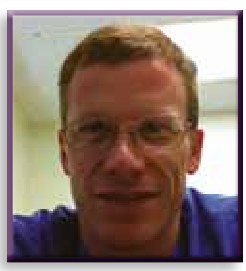

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