

**EVALUATION OF THE BONE INJECTION GUN  
FOR INTRAOSSEOUS  
INFUSION THERAPY IN ADULT CANINES**

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**Objective**— Evaluation of the Bone Injection Gun (BIG) for rapid placement of an intraosseous cannula through impact penetration of the bone and compare it to a standard Jamshidi bone marrow needle (JBMN).

**Study Design**— In vivo randomized study.

**Animals**— Forty-eight mature dogs.

**Methods**— During terminal surgical laboratories dogs were randomly assigned to two groups and had an intraosseous cannula placed using the BIG or JBMN in the medial aspect of the proximal tibia. Parameters measured during placement included insertion success, time required for placement, and alterations in respiratory rate (RR), heart rate (HR), and Doppler measured blood pressure (BP). Following placement, maintenance fluids were administered to six dogs from each group and fluids were administered under pressure to six dogs from each group to compare rates of delivery through each cannula type. Following euthanasia at the conclusion of the study the tibias were harvested to evaluate and compare the histopathologic consequences of cannula placement.

**Results**— Successful placement occurred in 20/24 (83.3%) for the BIG and 23/24 (95.8%) for the JBMN, which was not significantly different ( $p = 0.3475$ ). Time required for placement was significantly less ( $p = 0.0024$ ) for the BIG (0 = 22.4 sec) over the JBMN (0 = 42.0 sec). Significant increases in RR were seen for both groups and in the HR for the BIG group but significant differences in these variables were not noted between the groups. There was no difference in the fluid delivery rates between the two groups. Mean rate of pressurized fluid administration was similar for both groups and not significantly different. Histopathologic evaluation indicated two distinct patterns of cortical bone damage but the clinical significance is uncertain.

**Conclusions**— The BIG effectively provides rapid access to the intraosseous space and vascular system in the mature canine.

**Clinical Relevance**— Intraosseous infusion of fluids, blood products and various drugs has been shown to be very effective as an alternative to intravenous infusion. The BIG can provide rapid access for emergency drug and fluid delivery.

Successful treatment of many emergency conditions is contingent upon gaining rapid access to the systemic vascular space and delivering resuscitative drugs or fluids. However, vascular collapse or inadequate cardiac output that may accompany many emergency conditions may impair access to the peripheral vascular system, which is the most commonly used route of emergency drug and fluid administration. Other conditions that may preclude gaining access to the vascular space are small patient size, morbid obesity, trauma to common sites for intravenous catheters, and peripheral edema. Alternatives to peripheral vasculature administration include intratracheal, intraperitoneal, subcutaneous, and intraosseous routes. Significant drawbacks to the intratracheal route are that only small volumes of supportive drugs can be administered and not the larger volume of fluids that are generally required.<sup>1</sup> Also emergency support measures such as positive pressure ventilation and cardiac massage may have to be temporarily halted during drug administration.<sup>2-4</sup> The intraperitoneal and subcutaneous routes are inadequate when peripheral circulation is reduced or vascular collapse exists which may result in poor absorption into the systemic circulation.<sup>1</sup> The rigid, tubular nature of bones with well-defined venous drainage that empties quickly into the systemic circulation provides a means to overcome the problem of inaccessible central or peripheral veins as well as the problems discussed with the alternative routes. Intraosseous infusion (IOI) of fluids, blood products and various drugs has been shown to be very effective as an alternative to intravenous infusion.<sup>1,5-14</sup> An additional advantage to the intraosseous route is the relative ease and speed that access to the vascular space can be attained. Recent studies have shown that medical and paramedical personnel, even if inexperienced in the technique of intraosseous cannula placement, can gain access to the intraosseous space using a variety of cannula types within 2.5 minutes and generally the time required is about one minute.<sup>11,15</sup> The advantages of IOI have prompted the American Heart Association, the American Academy of Pediatrics, and the American College of Surgeons to recommend IOI in emergency situations when venous access is not immediately possible.<sup>14,16</sup>

The purpose of this study was to evaluate a relatively new device, the Bone Injection Gun (WaisMed Ltd., GMS Marketing, West Hempstead, NY 11552), that allows rapid placement of an IOI needle through impact penetration. We hypothesized that this new device will allow more

rapid access to the intraosseous space than conventional bone marrow needles that require a surgical approach through the skin and subcutaneous tissues and a boring technique for placement into the bone. Further, the speed of placement will result in less apparent discomfort than conventional placement. Additionally an attempt was made to determine maximum isotonic fluid delivery rate and evaluate the pathologic consequences of impact penetration of bone.

### **Materials and Methods**

The Institutional Animal Care and Use Committee of Kansas State University reviewed the proposals for animal care and experimental protocol and granted approval prior to the initiation of the study.

Concurrent with a surgical training laboratory that accommodated 12 dogs per laboratory period, 48, mature canines were randomly divided into two groups of 24. All dogs were premedicated with acepromazine (0.1 mg/kg subcutaneously[SC]), meperidine (4mg/kg SC), and atropine (0.04 mg/kg SC). Anesthesia was induced using thiopental sodium (10 mg/kg intravenously [IV]) followed by endotracheal intubation and maintenance with halothane and oxygen. Student anesthetists performed the anesthesia and monitored each of the dogs at five-minute intervals for alterations in respiratory rate, heart rate, ocular position, and jaw tone. Alterations indicating less than a surgical anesthetic plane were addressed immediately with the help of a faculty anesthesiologist or staff anesthetist. The first group received a 15 gauge, intraosseous cannula placed into the medial aspect of the right or left proximal tibial metaphysis using a standard Jamshidi bone marrow needle (JBMN). The placement technique was standardized and included a sterile presurgical preparation of the skin and a stab incision approach through the skin and subcutaneous tissue to the bone. The JBMN was then inserted through the incision to the bone and rotated alternately clockwise and counter-clockwise while applying pressure to the bone. Rotations were stopped when an abrupt loss of resistance was felt. The second group likewise received a 15 gauge intraosseous cannula placed in the medial aspect of the right or left proximal tibia using an automatic device, the Bone Injection Gun (BIG), which allows rapid placement of an IOI needle through impact penetration (Fig 1). This device

uses a precharged coil to propel a trocar-needle combination at high speed through the skin, subcutaneous tissues, and bone cortex. Adjusting the outer sleeve of the BIG to the desired depth before placement can control the degree of trocar-needle penetration (Fig 2). In order to estimate the proper depth for placement, tibial radiographs (cranial-caudal view) from 30 randomly selected dogs seen at the veterinary teaching hospital for various orthopedic problems were evaluated. The radiographs were separated according to the weight in kilograms of the imaged dog and a chart indicating median depth and range for dogs in four weight classes was produced (Table1). The weight of the dogs in the BIG group was compared to the chart and the BIG was adjusted for penetration to the corresponding depth. A pre-surgical preparation of the skin was performed but an approach to the bone was not performed. The device was placed in contact with the skin and perpendicular to the bone surface. The trigger was pulled and the BIG was fired to place the cannula. Once in place the trocars from both cannula types were withdrawn and aspiration of 2.0 cc of marrow confirmed proper placement. Data recorded during placement included success of cannula insertion, time required for placement (defined as the time from contact of scalpel blade or BIG to the skin to withdrawal of bone marrow), and changes in the physiologic parameters of heart rate (HR), respiratory rate (RR), and Doppler blood pressure (DBP).

After assuring proper placement, six of the dogs from each group received lactated Ringers solution at 10 ml/kg/hr via gravity flow through the intraosseous cannula during the perioperative period. The remaining dogs from each group received perioperative lactated Ringers at the same rate delivered through an intravenous catheter placed in a cephalic vein in one of the forelimbs. At the conclusion of the surgical training laboratory six dogs received intraosseous lactated Ringers delivered under a constant pressure of 300 mm Hg for a period of eight minutes in an effort to determine the maximum rate for isotonic crystalloid fluid administration.

Following completion of the surgical training exercises and intraosseous fluid administration trials the dogs were humanely euthanized using an overdose of pentobarbital

sodium (88 mg/kg IV). The tibias used for intraosseous cannula placement were harvested and stored in 10% neutral buffered formalin for later histopathologic evaluation.

Statistical evaluation of the data was performed using nonparametric methods.

Comparisons of the vital parameters between pre-placement and post-placement of the cannula within the two groups were made using Wilcoxon signed rank test. Comparisons between the two groups were made using Fisher's exact test for success of cannula placement and Wilcoxon-Mann-Whitney test for differences in vital parameters. Significance was established when  $p \leq 0.05$ .

## Results

All of the dogs were judged to be mature based on the presence of complete adult dentition. Exact ages could not be determined due to a lack of this information being provided by the supplier of the dogs. Thirty-three (69%) of the dogs were female and 15 (31%) were male. The size of the dogs ranged from 10.2 kg to 37.1 kg. There were no premature deaths during each of the laboratory periods.

Successful placement of the intraosseous cannula occurred in 23 / 24 (95.8%) in the JBMN group and 20 / 24 (83.3%) BIG group. The difference for successful placement was not significant ( $p = 0.3475$ ). Cannula placement was significantly faster with the BIG than with the JBMN ( $p = 0.0024$ ). The mean time for cannula placement in the BIG group was 22.4 seconds (SD = 8.2) while the average for the JBMN group was 42.0 seconds (SD = 28.1).

There was a significant increase in the RR during placement in both groups. The mean increase in the JBMN group was 6 respirations / minute (rpm)  $\pm$  11 rpm ( $p = 0.0045$ ) and the increase in the BIG group was 11 rpm  $\pm$  18 rpm ( $p = 0.0006$ ). There was no significant difference between the two groups for the increase in RR ( $p = .4307$ ). There was a significant increase in the HR for the BIG group but not for the JBMN group. The mean increase in HR for the BIG group was 6 beats / minute (bpm)  $\pm$  10 bpm ( $p = 0.0249$ ) while the mean increase for the JBMN group was less than  $\frac{1}{2}$  bpm ( $p = .3979$ ). There was no difference in the heart rate increase noted between the between the two groups ( $p = .1640$ ). The DBP did not change significantly for either

group during cannula insertion and there was no difference between the groups ( $p = .9195$ ). The mean blood pressure for the JBMN group actually decreased by 0.18 mm Hg ( $p = .3735$ ) and in the BIG group increased by 1.78 mm Hg ( $p = .4950$ ).

Fluid delivery via gravity flow through the intraosseous cannulas was successful for the six dogs from each group. However, in 2 dogs from the BIG group and 3 dogs from the JBMN group the fluid flow would noticeably slow. Using a 3 cc heparinized saline filled syringe the cannula was flushed under pressure and adequate flow re-established.

Volumes and rates of intraosseous fluid delivery under pressure were very similar for both groups. One dog in the BIG group experienced extensive fluid extravasation from the intraosseous space and therefore the data was excluded. The mean total volume delivered through the JBMN was 190.5 mls and through the BIG was 220.5 mls. The fluid delivery rates were extremely close for both groups. The rate for the JBMN group was 74.55 mls/kg/hr and for the BIG group was 76.41 mls/kg/hr.

Grossly the entry points of the two cannula types could not be differentiated. Histopathologic evaluation of sections of the tibia containing the cannula tracts was performed following decalcification and staining with hematoxylin and eosin. The microscopic damage to the bone showed two distinct patterns secondary to cannula placement. Placement with the BIG induced microfractures that were commonly seen extending away from both sides of the cannula tract towards the endosteal surface in a diagonal pattern (Fig 3). This would effectively create a crater circumferentially around the tract with the largest diameter on the endosteal surface. The tracts from the JBMN showed less prominent microfractures but there was evidence of bone debris and some hemorrhage (Fig 4) that may be consistent with wobbling during insertion.

## **Discussion**

The lower success rate for placement with the BIG is very likely due to the initial lack of familiarity with the device. When the failure incidents were examined it was found that they all occurred during the first laboratory period. Although the BIG is quite easy to operate there was an apparent learning curve associated with the use of the unfamiliar technology. This indicates the

necessity of becoming familiar with the device prior to use in an emergency situation in order to reduce the possibility of improper placement. Another possible reason for failure of proper placement is inadequate identification of appropriate landmarks. This possibility is supported by the results in a five-year study evaluating prehospital intraosseous infusions in human medicine where errors in identifying landmarks was one of the most frequent causes of unsuccessful placement.<sup>14</sup> Initially the JBMN was subjectively easier to use but after becoming accustomed to the device there were no other failures. The one failure using the JBMN was due to penetration of both the cis and trans cortex. This was also a likely result of failure to properly identify landmarks.

Rapid access to the vascular space is imperative in emergency situations. This study has shown that the time required for placement was significantly less for the BIG. The reasons for the significant difference are quite obvious. The BIG technique does not require an incisional approach to the cortical surface of the bone nor is the repetitive twisting motion required. Simple depression of the trigger releases the spring mechanism and the trocar-cannula is instantly propelled through the skin, subcutaneous tissue, and bone. The clinical significance of the difference in the mean placement times between the two methods is difficult to determine. However, in a recent study of IOI devices, which included the BIG and JBMN, more emergency paramedical personnel chose the BIG as their first or second preference when the characteristics of simplicity, accuracy, and speed of placement were combined.<sup>15</sup>

The alterations in some of the monitored physiologic parameters were not completely unexpected. A previous study also reported, during ostensibly adequate anesthesia, an increase in HR, RR and blood pressure during insertion of an intraosseous device.<sup>2</sup> There was no attempt in the study to determine if the increases were significant, the increases were merely noted. This was inferred to be an indication of the painful nature of intraosseous cannula placement and the inference was used to recommend the use of local anesthetics during placement in conscious animals. In the current study the parameters that exhibited a significant increase were RR for both groups and HR for the BIG group. The DBP did not change appreciably for either group. It is reasonable to assume the variable response to the stimulus was due to differences in

anesthetic depth for each case. Despite attempts to assure a similar anesthetic depth, individual variation in response to anesthetic drugs, variability in observed patient response to noxious stimulus, and inexperience of the monitoring individual likely resulted in an apparent disparity of anesthetic levels. This may also explain why there was no significant difference in the altered parameters between the two groups. It was somewhat surprising that there was an increase in these parameters in the BIG group. Work using the BIG in the human field has reported that pain in the conscious patient was related more to the infusion of fluids under pressure and that placement of the intraosseous cannula via impact penetration is nearly painless. The high speed of insertion is theorized to contribute to a decrease in the painful stimulus.<sup>8,16</sup> However in these papers the use of a local anesthetic infiltration in the skin and periosteum was mentioned to reduce the pain on insertion. The changes in the vital parameters noted in this study support the inference that intraosseous cannula placement is painful and proper steps should be taken to prevent unnecessary discomfort.

An increase in intraosseous pressure associated with IOI into the proximal tibia of conscious goats has been found to contribute to clinical signs of limb discomfort.<sup>17</sup> There were no elevations in the monitored parameters of the six dogs during high-pressure infusion. It is possible that the level of anesthesia was sufficient at the time of infusion that the stimulus was not perceived.

This study has shown that fluids can be administered by gravity flow into the intraosseous space. However, periodic pressurized flushing of the cannula with heparinized saline may be necessary to maintain patency. Fluid delivery to dogs in emergency situations often requires rates of up to 90 ml/kg/hr.<sup>1,18</sup> The fluid rate achieved during 300 mm Hg pressure infusion did not reach the recommended rate. This is likely due to the resistance to flow at or near the venous exit points from the intraosseous cavity.<sup>17</sup> Intraosseous flow rates are primarily effected by the flow through the medullary cavity.<sup>12</sup> The findings in this study concur with others and indicate that intraosseous infusion of isotonic crystalloids through a single cannula may not be sufficient as the definitive means for rapid volume replacement.<sup>19</sup> However, the volume of fluid that can be given

may aid in gaining access to other peripheral veins or through the use of multiple IOI cannulas, sufficient rates may be achieved.

The histopathologic findings show that intraosseous cannula placement using the two methods creates different types of cortical damage. It has been shown that as a projectile perforates bone, a crater or cone lesion is created with the larger diameter at the exit point.<sup>20, 21</sup> The characteristics of the bone damage created by impact penetration was essentially the same. Histopathologically, the microfractures seen extending away from the cannula tract in a diagonal pattern would translate into a cone shape when viewed in three dimensions. This would be similar to the crater caused by a projectile hitting a pane of glass.<sup>20</sup> This type of bone damage was consistent within the BIG group. Structural damage caused by insertion of the JBMN would be similar to the damage seen when smooth orthopedic fixation pins are inserted by hand.<sup>22</sup> It has been shown that wobble during placement, which is also likely with JBMN placement, may contribute to the cortical damage.<sup>23</sup> It is difficult to speculate from this study if one type of damage is clinically more significant than the other.

The technique and value of IOI of fluids and drugs has been known for many years however, routine use of this potentially lifesaving procedure is relatively rare. The limited use of IOI in veterinary medicine seems to parallel its use in the human field. A recent study in the human field concerning IOI in adults has shown that despite a relatively high (74%) awareness of the technique as an option in resuscitative efforts, very few (7%) actually used the technique. Similarly, in the 157 emergency medicine departments surveyed that actively trained the medical and paramedical staff, only 11% taught the technique of emergency IOI.<sup>24</sup> In the author's experience at five veterinary teaching hospitals the value is mentioned rarely and the technique is only briefly described if at all. Reasons for limited use include lack of familiarity with the technique and concern or fear of producing unwanted complications.<sup>16</sup> Potential complications include introducing infection into the bone, inducing fat embolism, compartment syndrome, and perhaps causing pain and discomfort. A search of the literature reveals the complication rate for IOI may be less than with standard intravenous infusion. A review of more than 4000 cases of IOI detected a 0.6% bone infection rate.<sup>1,2,6,7,11,12,16</sup> This is considerably less than the 3.7%

infection rate seen with intravenous infusions.<sup>16, 25</sup> Fat embolization seems more an academic concern in that despite knowing embolization can occur there has been no reports of clinical problems.<sup>26</sup> One study evaluating IOI during cardiopulmonary resuscitation (CPR) has shown that the incidence of fat embolization was no higher when IOI was used than when CPR was performed without IOI.<sup>27</sup> Another potential complication, which is relatively uncommon and not reported clinically in animals, is compartment syndrome. This may be due to extravasation of fluids during prolonged infusion or failure of the microvasculature within muscles adjacent to the bone.<sup>13,28-30</sup>

The BIG has been shown to be an effective means of gaining rapid access to the intraosseous space for emergency fluid and drug administration. Proper training with this device would diminish possible failure of adequate placement. The clinical significance of the differences between the BIG and the JBMN cannot be determined by this study.

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Table 1. Median depths and ranges for impact penetration of BIG trocar-cannula

<u>Weight (kg)</u>	<u>Median depth (cm)</u>	<u>Range (cm)</u>
0 – 13.6	0.4	0.3 – 0.6
13.7 – 22.7	0.4	0.4 – 0.5
22.8 – 45.5	0.7	0.5 – 0.8
45.5 +	1.0	1.0

Fig 1. Bone Injection Gun and intraosseous cannula (open arrow) with trocar (arrowhead). The assembled gun shows adjustable sleeve (large arrow) for varying the depth of trocar-cannula penetration and the trigger assembly with safety device (small arrow).

Fig 2. Exploded view of the Bone Injection Gun. Left to right are the safety catch pin, housing assembly with adjustment sleeve and end cap, trigger assembly and spring coil with trocar grip, plunger device for compressing the spring, and the trocar and cannula. Note the variable depth graduations on the housing assembly (open arrow).