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Minimally Invasive Plate Osteosynthesis (MIPO) Applications in Long Bone Fractures of the Cats and Dogs

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Abstract
In this study, it was aimed to evaluate the treatment of long bone fractures of cats and dogs by minimally invasive plate osteosynthesis (MIPO), guided by radiological and walking-weight bearing criteria. For this purpose, 6 dogs and 1 cat, were operated according to MIPO procedures. After general anesthesia with butorphanol-propofol-sevoflurane, the fragments were aligned with closed reduction, and a MIPO plate was placed periostally via the created soft tissue tunnel. Fracture healing was assessed postoperatively at 0, 7, 14, 30 and 45 days by radiographic examination and walking-weight bearing scales. From the controls made on the 14th day, it was observed that all the cases could walk. The average time for radiographic union of 7 cases were found to be 47.42 (±4.98) days. As a result, MIPO technique was considered to be an alternative to traditional -open- plate osteosynthesis methods in the treatment fractures of cats and dogs.

Keywords: Fracture, Fracture healing, Osteosynthesis, MIPO.

INTRODUCTION

Although different methods have been improved for the treatment of long bone fractures in the orthopedic surgery since the beginning of modern surgery, the most widely used method is “open reduction and internal fixation” (ORIF) in veterinary orthopedic surgery. A perfect anatomical reduction is provided in ORIF, since bone fracture is aligned by sighting the fragments and fixing them directly by the surgeon. In this technique, however, it is always possible to further traumatize the fracture region -because of the large surgical dissection- and impair its vascular supply during surgical approach or fracture reduction, resulting in a delayed bone healing, non-union or an increased rate of complications. For example, radius-ulna and tibia has limited soft tissue cover, this situation limits peripheral vascular supply, leading to an increased rate (18%>) of complications like nonunion, osteomyelitis, or loss of fixation when ORIF is applied (Boone et al. 1986, Dudley et al. 1997, Nolte et al 2005, Rovesti et al. 2007). In order to avoid these complications, the idea of biological osteosynthesis was born, which envisions "closed reduction" instead of "open reduction" and "relative rigidity" instead of "absolute rigidity" in non-juxtaarticular long bones fractures. “Biological osteosynthesis” that is based on the doctrine “open but do not touch” is based on four basic principles. These include the use of closed reduction techniques to keeping soft tissue injury at minimum, providing a fixation with reasonable rigidity/stability, and early recovery of function of fractured extremities (Perren 2004, Altunatmaz 2004, Barnhart 2020). Compliance with these principles ensures that fracture hematoma and fracture fragments are not directly traumatized by the surgeon and the biological processes of bone healing are not interrupted, thereby reducing complications.

Fixing the fracture with a plate-screw system without surgical opening the fracture zone is termed as minimal invasive plate osteosynthesis (MIPO). In MIPO, a locked plate-screw unite is used as an periosteally placed external fixator (Guiot and Déjardin 2020, Gautier 2009, Tong et al. 2020, Yurdakul and Sağlam 2009). In MIPO, there should be bone segments that are strong enough to insert at least two screws at the distal and proximal of the fracture. Therefore, juxta articular or intraarticular fractures are not suitable for performing the MIPO technique.

In veterinary orthopedics, diaphyseal fractures of the radius-ulna and tibia are the most suitable cases for MIPO. Due to the strong muscle groups around the femur and humerus, they are not ideal targets for closed reduction and MIPO. Also, since it is not possible to reduce fragments with closed reduction, MIPO is not applied in every kind of old fractures (Hudson et al. 2009, Guiot and Déjardin 2011, Yalız 2016).

In MIPO, conventional dynamic compression plates (DCP) (Kaya 2003) can be as well as locked plates that contact with the periosteum limitedly (LC-LDCP) or minimal invasive stabilization plate (MISP) specially produced for MIPO.

In MIPO, as the plate will work like an internal external fixator; using a long plate -as long as possible- provides a biomechanical advantage. Using a long plate reduces the stress load between plate and screws, thus reducing the risk of implant failure (Gönç et al. 2012). In other words, the ratio of plate length to bone length [Plate-Bridging Density (PBD)] should be less than 0.91±0.05 (Yalız 2016, Cabassu 2001, Schmökel et al. 2007, Tanaka 2007, Hudson et al. 2020).

MATERIALS AND METHODS

The study cases consisted of 6 dogs and 1 cat that were brought to the "Çanakkale Petcity Clinic" by their owners and diagnosed fractures radiologically. The data about the patients are detailed in Table 1. Before the operation, owners were informed about the type of the fracture, operation technique, possible complications and then the information and consent form was signed.

Table 1. Detailed data of the cases

#	Signalment	Age(month)	BW (kg)	Fracture type and localization	Traumatic Cause
1	Cat, Mix, ♂	27	4	Diaphyseal, transvers, femur (R)	HRS
2	Dog, ASD, ♂	5	17	Diaphyseal, oblique, tibia (L), CF	TA
3	Dog, Mix, ♂	23	25	Diaphyseal, oblique, femur (R) CF	TA
4	Dog, CS, ♀	25	16	Diaphyseal, fragmented, tibia (R) CF	TA
5	Dog, GS, ♀	33	35	Diaphyseal, oblique, radius (L) CF	TA
6	Dog, PR, ♂	26	20	Distal diaphyseal, transvers, radius-ulna (R) CF	TA
7	Dog, PR, ♂	22	20	Distal diaphyseal, transvers, radius-ulna (L) CF	TA

#: Case number, **ASD:** Anatolian Shepherd Dog, **CS:** Cocker Spaniel, **GS:** German Shepherd, **PR:** Pointer, **BW:** Body Weigth, **R:** Rigtht, **L:** Left, **CF:** Closed Fracture, **HRS:** High Rise Syndrome, **TA:** Traffic Accident

The animals was anesthetised with 0.1 mg/kg butorphanol (Butomidor®, Sol., Interhas, Istanbul, Turkey), 10 mg/kg propofol (Propofol®, % 1, 20 ml amp., Fresenius Kabi, Sweden) and sevoflurane (Sojourn®, Adeka, Turkey) protocol. Analgesia was provided by administering 0.2 mg/kg meloxicam (Maxicam®, Sanovel, Turkey) via subcutaneously. Postoperative antibiotic coverage was provided by administering 8 mg/kg clindamycin ((Klindan®, Bilim, Turkey) and 10 mg/kg amoxicillin clavulanate (Synulox® Pfizer, Turkey) for 5 days.

All cases except the case number 3 had displaced fracture fragments. Among the seven cases, only the case number 4 had a "segmental" fracture (Figure 1).

Figure 1. Preoperative radiograms of the cases 1-3 and 5-7

MIPO Procedure

The technique described by Kowalewski (2020) was used in femur fractures for MIPO. The technique described by Beale and McCally (2020) was used to apply MIPO for tibial fractures. For the radius-ulna fractures, Hudson (Hudson et al. 2020) technique was used to perform MIPO.

Displaced bone fragments were aligned by traction and correction maneuvers of extremity and than the alignment of fracture was checked radiologically. When alignment was completed, the plate was placed into the periosteal tunnel and fixed with locked screws. After checking the final position of bone fragments, plate and screw placement radiologically, the wound was closed routinely. The Robert-Jones bandage was applied to the extremity after the operation, no exercise restriction was advised.

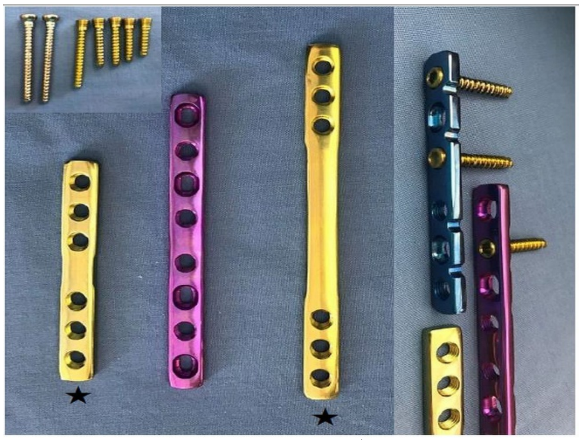

Figure 2. The plates (DCP, LDCP, MISP*) used in the study.

Bone and fragmentation length, plate type, plate length and number of holes and number of screws were recorded for every cases. These data were used in the calculation of "screw-plate density (the ratio of screws used to the number of holes on the plate, SPD)", "plate-bridging density (the ratio of plate length to broken bone length, PBD)", and "plate-fracture density (the ratio of plate length to the length of the fragmentation line (PFD)" parameters for each case (Gautier 2009, Tong and Bavonratanavech 2007, Guiot and Déjardin 2011, Yalız 2016). Plate specifications and also SPD, PBD and PFD calculations are shown in Table 2.

Table 2. Plate specifications and related other parameters

Fracture Type	Bone Length	Plate Type	Plate Length	Plate Tickness	Hole Number	SPD	PBD	PFD	BUD
CN1, Diaphyseal, transvers, femur	11.6	LCP	8 cm	2.7 mm	8	0.6	0.68	8.8	45
CN2, Diaphyseal, oblique, tibia	11.7	MISP	9.6 cm	2.7 mm	6	0.6	0.82	5	40
CN3, Diaphyseal, oblique, femur	16.5	MISP	12 cm	2.7 mm	6	1	0.72	12	45
CN4, Diaphyseal, fragmented, tibia	12.7	MISP	9.6 cm	2.7 mm	6	1	0.75	4.5	44
CN5, Diaphyseal, oblique, radius	19.15	LCP	15.5 cm	3.5 mm	12	0.5	0.8	11.9	53
CN6, Distal diaphyseal, transvers, antebrachium	16.3	MISP	12 cm	2.7 mm	6	0.8	0.73	10	54
CN7, Distal diaphyseal, transvers, radius-ulna	16.3	MISP	12 cm	2.7 mm	6	1	0.73	10	50

CN: Case Number, **LCP:** Limited Contact Plate, **MISP:** Minimally Invasive Stabilisation Plate,**SPD:** Screw Plate Dansity, **PBD:** Plate Bridging Dansity, **PFD:** Plate Fragment Dansity, **BUD:** Bone Union Day (Radiologically)

Fracture healing was evaluated by radiological examination and walking/weight bearing scores on days 0, 7, 14, 30, and 45 (Figure 3). At the radiological controls, the times of complete fracture healing (bone union day, BUD) were recorded.

Fracture healing and walking/weight-bearing capability evaluated with two different score systems, both developed by Öztaş and Avki (2015). Evaluation criteria, walking/weight-bearing and radiological bone healing scores were shown in Table 3.

Study data were analyzed and their mean values (± SD) were calculated using the Minitab™ (version 17.0, Philadelphia) software on Windows™.

Figure 3. Case 1, Bone healing phases.

Table 3. Walking/weight bearing and radiological examination parameters and scores.

<table>
<tr><th rowspan="2">Score</th><th rowspan="2">Walking and weigth bearing parameters</th><th colspan="5">Days</th></tr>
<tr><th>0.</th><th>7.</th><th>14.</th><th>30.</th><th>45.</th></tr>
<tr><td>1</td><td>The patient cannot stand and was brought by the owner, carried on the lap.</td><td rowspan="6">4.85 (±0.14)</td><td rowspan="6">5.85 (±0.14)</td><td rowspan="6">6 (±0)</td><td rowspan="6">6 (±0)</td><td rowspan="6">6 (±0)</td></tr>
<tr><td>2</td><td>The patient can stand with support, but the operated leg is suspended.</td></tr>
<tr><td>3</td><td>The patient can stand with support and touch the operated extremity to the ground, but extremity not weight bearing.</td></tr>
<tr><td>4</td><td>The patient can walk, but the relevant leg is suspended.</td></tr>
<tr><td>5</td><td>The patient can use the operated limb, but the steps are short and the animal limping. Limited weight bearing.</td></tr>
<tr><td>6</td><td>The patient can use the operated limb and walk normally. Full weight bearing.</td></tr>
<tr><td></td><td colspan="6">Radiologically evaluation parameters</td></tr>
<tr><td>1</td><td>The fracture line is visible and there is no callus tissue around the fracture line</td><td rowspan="4">1 (±0)</td><td rowspan="4">1.42 (±0.20)</td><td rowspan="4">2.28 (±0.18)</td><td rowspan="4">3.28 (±0.18)</td><td rowspan="4">3.85 (±0.14)</td></tr>
<tr><td>2</td><td>The fracture line is visible and there is no callus tissue around the fracture line</td></tr>
<tr><td>3</td><td>The fracture line is partially visible and there is a small amount of periosteal and endosteal callus tissue.</td></tr>
<tr><td>4</td><td>The fracture line cannot be seen and there is periosteal and endosteal callus tissue.</td></tr>
</table>

RESULTS

Intraoperative and Postoperative Findings

A LCP was used for the cases number one and five, MISP without screw holes in its middle segment that was specifically designed for minimal invasive plate osteosynthesis was used for the rest of the cases. In the case number two, it was possible to place two screws to each of the proximal and distal fragments while in the others three screws were placed to each of the proximal and distal fragments, or three locked screws were bi-cortically placed to the proximal fragment and two screws to the distal fragment.

SPD, PBD and PFD values (±SD) were calculated (Table 2) to determine the reliability of interfragmentary stability attained by MIPO. The seven cases had a mean SPD of 0.78 (±0.2), a mean PBD of 0.74 (±0.04), and a mean PFD of 8.8 (±2.81).

The mean (±SD) scores of the radiological examination and walking/weight bearing ability on the days 0, 7, 14, 30, and 45 were shown on Table 3.

None of the cases developed surgical site infection or any complication related to failured fixation due to a loosened screw or plate fracture. All cases could walk using their MIPO-applied extremity at the 14th day control.

DISCUSSION

The philosophy of fracture treatment has witnessed some paradigm shifts in recent years. The osteosynthesis procedures of AO/ASIF, which have been accepted as a "gold standard" for a long time, use large surgical dissection to access a broken bone and achieve a stable fixation by complete anatomic reduction and interfragmentary compression. It is already known; however, such procedures cause additional damage to bone hematoma, circulation, adjacent soft tissues, and fragments (Perren 2002, Barnhart 2020). In the line of these data, efforts have been started to develop novel techniques that ensure adequate stability and do not jeopardize organism's regenerative functions. Another development that has accelerated research on this subject is the understanding that fixation methods allowing axial motion at the fracture line on micro level allows the formation of a superior callus tissue in terms of quality and maturation than systems providing absolute interfragmentary rigidity (Goodship and Kenwrigth 1985). These advances have re-popularized techniques keeping minimum operational tissue injury, such as external fixator, percutaneous nailing, and fixation with intramedullary locked nailing (Perren 2002, Barnhart 2020, Yalız 2016, Dejardin et al. 2020, Hudson et al 2020)

MIPO has evolved out of the idea of subcutaneous placement of AO plates to the fracture region without directly intervening it, in an attempt to use them as a type of subperiostal external fixator (Barnhart 2020). It has been reported that the MIPO technique, the form of plate osteosynthesis applied to biological fracture treatment, has yielded successful outcomes in long bone fractures in humans (Gönç et al 2012, Helfet et al. 1997, Mahiroğulları et al 2012).

MIPO ensures a significantly superior preservation of vascular network in and around the fracture region than the ORIF procedures. Thank to this feature, MIPO has been shown to accelerate fracture healing and reduce intraoperative contamination of the fracture region (Farouk et al. 1998, Xu et al. 2020, Baroncelli et al. 2012). In accordance with these data, the present study demonstrated that none of the patients undergoing osteosynthesis using the MIPO technique experienced infection or complicated fracture healing.

The MIPO technique aims to induce osteosynthesis without damage to the fracture hematoma and surrounding soft tissues, which are critical for the primary phase of fracture healing (Altunatmaz 2004, Gautier 2009, Tong and Bavonratanavech 2007, Peirone et al. 2020). The primary prerequisite of reaching the principle summarized as "open but do not touch" is the application MIPO in conjunction with closed reduction (Perren, 2002, Altunatmaz 2004, Maritato and Rovesti 2020, Redfern et al. 2004) Many techniques have been defined to perform closed reduction during MIPO[4,11,14,34]. In this study, traction of the limb and axial alignment of fracture fragments with manual maneuvers were attempted for closed reduction of the fracture before plate was placed. Although there was a marked displacement of fracture fragments in all cases except for the case number three, manually correction could be sufficiently achieved to perform plate fixation. Even in the cases number 1 (Figure 3.1A) and 5 (Figure 3.1E), where the displacement of fracture fragments was greatest, closed reduction using the above-mentioned technique was adequate for MIPO[32]. Hence, Peirone et al. (2020) stressed that, unlike the AROF technique, the MIPO technique does not primarily aim to achieve bone healing with a perfect reduction but contends with a reduction sufficient enough to allow secondary bone healing.

Studies stressing the importance of case selection for the success of the MIPO technique reported that the proximal and distal fragments should be of sufficient length to allow application of two screws to both fragments (Hudson et al. 2009, Guiot and Dejardin 2011, Yalız 2016). Those same studies also noted that filling holes on the plate with an excess number of screws is also be harmful since they would exert no effect on fixation stability, but they would disrupt bone and/or fracture hematoma (Hudson et al. 2009, Guiot and Dejardin 2011, Yalız 2016). Considering this information, case selection in this study was in compliance with the minimum screw number predicted for MIPO.

The ratio of the number of screws placed on the plate to the number of holes on the plate, in other words the SPD, is also taken into account while determining the compliance of the number of screws with the MIPO criteria. Hence, using too many screws is not recommended for MIPO. A plate-screw density of 0.40 would be sufficient for a relative fixation aimed by MIPO in distal or proximal diaphyseal fractures of the long bones (Gautier 2009, Hudson et al. 2009). In a study comprising 36 cases where feline and canine non-articular tibia fractures were studied (Guiot and Déjardin 2011), SPD values ranging between 0.15 and 0.64 yielded favorable outcomes. Similarly, Yalız (2016) who treated 8 canine tibia fractures reported favorable outcomes with an SPD value of 0.54. In the present study a mean SPD value of 0.78 (±0.2) was calculated for 7 cases. Although this SPD value was similar to that reported by Guiot and Déjardin (2020) and Yalız (2016) it was noted to be somewhat higher. This was attributed to the use of MISPs in the majority of cases (n=5) despite the use of multi-hole LCP in 2 cases (Table 3.2). Indeed, MISPs specifically produced for MIPO have no screw holes in their mid-section. Such a structural feature causes an increased SPD value of minimal invasive stabilization plates compared to other plates having screw holes across their entire lengths.

In the MIPO technique plates as long as possible are used to bridge the fracture line. This ensures a lower likelihood for implant failure by reducing the stress load between the plate and the screw. One can decide whether the length of a selected plate is adequate for bridging a fracture line by calculating the ratio of the plate length to bone length [plate bridging density (PKD)], which should be ideally below 0.91±0.05 in average. This both ensures an ideal fixation flexibility for union and reduces the likelihood of plate fracture (Cabassu 2001, Tanaka 2007). In the present study, a mean PBD value of 0.74 (±0.04) found for 7 cases was interpreted that appropriate plates were selected for the MIPO technique.

In the MIPO technique, the ratio of the plate length to the fragmentation length (PFR) is also checked for gauging the adequacy of a selected plate's length (Gautier 2009, Hudson et al 2009, Yalız 2016, Cabassu 2001, Tanaka 2007). Gautier (2009) reported that a plate should be at least 2-3 times longer than the total length of fracture lines for fragmented fractures and at least 8-10 times longer than the fracture line for simple fractures. In the present study a mean PFD value of 8.8 (±2.81) was obtained for the whole study population. An individual analysis of each case with the information provided by Gautier (2009) in mind revealed that the length of the selected plate was 4.5 times greater than the total length of the fracture lines in the case number 4, which had a fragmented diaphyseal tibia fracture, and 9.64 (±1.04) times greater in average in the other 6 cases, which had a simple fracture with a single fracture line. This was interpreted that the lengths of the selected plates were suitable for MIPO standards (Gautier 2009, Hudson et al 2009, Yalız 2016, Cabassu 2001, Tanaka 2007). There is a markedly limited body of information about the time to fracture healing among dogs and cats undergoing fracture treatment with MIPO. One of the two domestic studies (Yurdakul ve Sağlam 2009) reported that functional bone healing occurred between postoperative 46th and 82nd days in 11 cases. Yalız (2016) reported that tibia fractures showed radiographic healing between 45th and 50th days. Other studies in which feline and canine extremity fractures were treated with MIPO (Guiot and Déjardin 2011, Schmökel et al. 2007) satisfactory clinical and radiological bone healing was observed on 36th-45th days. Reems et al. (2003), in a group of 47 cases undergoing anatomic alignment with intramedullary nails followed by MIPO for fracture fixation, observed a mean healing time of 7.5 (±2.7) weeks for dogs and 4.8 (±1.3) weeks for cats. In agreement with the literature data presented above, this study also showed that all cases could step on the MIPO-applied extremity and normally walk. On the other hand, the mean radiological union time was 47.42 (±4.98) days.

Considered in conjunction with the findings of Boone et al. (1986) reporting a mean time to bone healing of 133 days for adult cats and dogs and 70 days for adolescent cats and dogs with long bone fractures treated with osteosynthesis with open reduction and plate implantation, our findings suggested that MIPO accelerates bone healing considerably.

It was concluded that MIPO may be an alternative to ORIF method for the treatment of feline and canine long bone fractures, but care should be exercised to select suitable cases for a successful MIPO procedure.

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Conflict of Interest
The authors declare that there is no conflict of interest in the content of the article

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