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RESEARCH ARTICLE

Comparison of Outcomes from Minimally Invasive Plate Osteosynthesis (MIPO) Versus Open Reduction and Internal Fixation (ORIF) in Radial Fracture Gap Models

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A B S T R A C T

The purpose of the present study was to evaluate fracture healing after minimally invasive plate osteosynthesis (MIPO) and open reduction and internal fixation (ORIF) via radiographic scoring, visual lameness scoring, weight bearing time, range of motion (ROM), experimentally. The experimental fracture gap models in this study were divided into two groups: six dogs in Group A received ORIF; four dogs in Group B received MIPO. For each animal, the age, sex, breed, body weight, and follow-up duration were recorded. Radiography results revealed that Group B recovered better than Group A. Visual lameness scoring and weight bearing time showed that animals in Group B were able to bear weight on the affected limb significantly faster than those in Group A. The ROM was higher in Group B than in Group A in the early stages and gradually increased in all dogs over the course of 12 weeks. In present study, radial fractures managed with MIPO showed more rapid recovery in the early healing stage than those managed with ORIF in clinical and functional outcomes.

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INTRODUCTION

In toy breed dogs, fractures of the radius and ulna are the third most common type of fracture (Hudson *et al.*, 2012; Pozzi *et al*., 2013; Townsend and Lewis, 2018) and pose a great risk for delayed union or nonunion (Piras *et al*., 2011; Baltzer *et al*., 2015; Aikawa *et al*., 2018). The method selected to repair radial fractures influences the course of healing. Repair of radial diaphyseal fractures using intramedullary pins should be avoided because it has been associated with healing complication rates as high as 80% (Aikawa *et al.*, 2018). There are several suitable fixation methods for radial fractures in small dogs, including open reduction and internal fixation (ORIF), external skeletal fixation (ESF), and minimally invasive plate osteosynthesis (MIPO) (Piras *et al*., 2011; Pozzi *et al*., 2013; Aikawa *et al*., 2018). Method selection depends on patient status, fracture configuration, and surgical environment.

ORIF is the most commonly used method and has produced good outcomes in the treatment of radial fractures (Pozzi *et al*., 2013). The protocol for ORIF methods requires large surgical exposure of the fracture site and precise anatomic reconstruction (Garofolo and Pozzi, 2013). However, this technique damages soft tissues and risks devascularization of the periosteum, which can delay healing. In addition, ORIF is associated with infections at the fracture site (Pozzi *et al*., 2013).

ESF is frequently recommended for the stabilization of radial fractures (Piras *et al*., 2011; Bierens *et al*., 2017). External fixation has the advantages of causing minimal damage to the injured region, maintaining bone length, minimizing atrophy formation in the bone and soft tissues, allowing complete weight-bearing on the healing bone, and localizing soft tissue trauma to the fracture line (Bierens *et al*., 2017). On the other hand, complications associated with ESF include loose pins, pin and tract breakage, and infection (Piras *et al*., 2011).

MIPO is a safe and common method with the advantages of minimizing soft tissue injury, blood loss, infection, and postoperative pain. Recent patterns in fracture treatment have focused on MIPO (Pozzi *et al*., 2013), which accommodates the biological environment to promote faster recovery, neovascularization, and increased callus formation (Garofolo and Pozzi, 2013; Bighan-Sadegh and Oryan, 2015). MIPO does not usually require anatomical reduction of the fracture. Instead, it applies a bone plate as a bridge fashion without surgically approaching the fracture site (Peirone *et al*., 2012). Recently, the use of MIPO has been reported for the treatment of radius and tibia fractures in small dogs and cats to reduce iatrogenic vascular destruction (Hudson *et al*., 2012; Pozzi *et al*., 2013; Craig *et al*., 2018). The purpose of this study was thus to compare the clinical and functional outcomes through radiographic evaluation, visual lameness scoring, weight bearing time and range of motion between ORIF and MIPO in radial fracture gap models.

MATERIALS AND METHODS

Study dogs: Ten healthy, adult beagles weighing from 7.8 to 11 kg (9.44±1.16 kg) were used in this study. This study was approved by the IACUC (CBNU 2015-061) of Chonbuk National University under strict guidelines. Group A (six dogs) received ORIF, and Group B (four dogs) received MIPO. The basic experimental model used a radius diaphysis transverse defect (10 mm in length) created using an oscillating saw (Fig. 1). Osteotomy was performed with caution to minimize peritoneum damage. After making of the fracture gap model, the dogs were in cage rest and used Robert Jones bandage 2 weeks before ORIF and MIPO surgery.

Surgical procedure

Minimally invasive plate osteosynthesis (MIPO): In dorsal recumbency, proximal and distal plate insertion was 2 to 4 cm near the elbow and carpal joints, respectively (Fig. 2A). Metzenbaum scissors and a periosteal elevator were used to create an epiperiosteal tunnel for plate insertion (Fig. 2B). The plate insertion started at the distal part and advanced along the cranial surface of the radius through the epiperiosteal tunnel (Fig. 2C). Proper positioning of the bone plate on the radius was assessed by fluoroscopy (Zen 2090 Pro, Genoray Co, Ltd, Sungnam, Korea) (Fig. 2D). Screws were inserted into both the proximal and distal holes in the bone plate (Fig. 2E). If screws needed to be placed into a plate hole, a stab incision was created over the desired plate hole using fluoroscopic guidance.

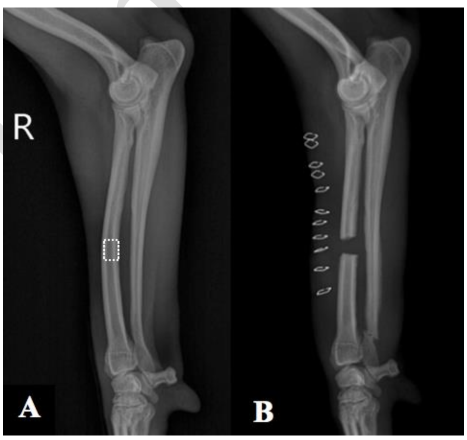

Fig 1: Mediolateral radiographs of forelimbs. (A) Normal forelimb. (B) Basic experimental model, a radial diaphysis transverse defect (10 mm in length) created using an oscillating saw.

Open reduction and internal fixation (ORIF): Under general anesthesia, the plate and screws were fixed with an extensive, open approach with direct reduction for mechanical and anatomical alignment following the AO manual of fracture management (Johnson *et al*., 2005).

Postoperative management: Robert Jones bandages with splints were applied for 7 days. Cold therapy was applied surrounding the surgical site for 20 min two times a day for three days. Ten days after the removal of suture materials, swimming therapy as rehabilitation was applied for 7 days to restore ROM and muscle mass. Leash walking was initiated 21 days postoperatively for about 7 days. The tramadol (3 mg/kg, Tramadol HCl, Shinpoong Pharm, Seoul, Korea) and meloxicam (0.02 mg/kg, Metacam, Boehringer Ingelheim, Ingelheim/Rhein, Germany) were administered for 3 days, the antibiotic cefazolin (22 mg/kg, Cefazolin sodium, Chongkundang Pharm, Seoul, Korea) for 5 days.

Evaluation

Radiographic evaluation: Radiographs were taken at 1, 2, 4, 8, 12, and 16 weeks after each operation, evaluating mediolateral and craniocaudal radiographic projections of each radius using the radiographic scoring system (Patel *et al*., 2014).

Visual lameness score: All dogs were evaluated at stance, walk, and trot using a numerical rating scale with six grades of lameness (Quinn *et al*., 2007). This analysis was performed at 4, 8, 12, and 16 weeks.

Weight bearing time: All dogs were evaluated for weight loading using 3 grades. This analysis was performed after 1, 2, 3, 4, 6, 8 and 12 weeks.

Range of motion (ROM): The ROMs of the elbow joint and carpal joint were measured for all forelimbs. Flexion and extension angles were recorded in triplicate. To calculate the amplitude of the ROM, the angle of flexion was subtracted from the angle of extension. ROM was measured 4, 8, 12 and 16 weeks postoperatively.

Statistical analysis: All data were analyzed using repeated measures of analysis of variance with subsequent post-hoc pair wise comparisons (Bonferroni method). All statistical analysis was performed using SPSS software (SPSS, INC., Chicago, IL, USA) or Graphpad prism 5.0 (Graphpad Software, Inc., San Diego, CA, USA). P values less than 0.05 were considered significant.

RESULTS

Evaluation

Radiographic evaluation: Three independent radiologists and two surgeons scored the radiologic improvement at 1, 2, 4, 8, 12, and 16 weeks. Radiographs from the ORIF (Group A; Fig. 3A) and MIPO (Group B; Fig. 3B) experimental dogs were taken at 1, 2, 4, 8, 12, and 16 weeks. Group B recovered better than Group A, but that difference was not significant in any measurement period (Fig. 4).

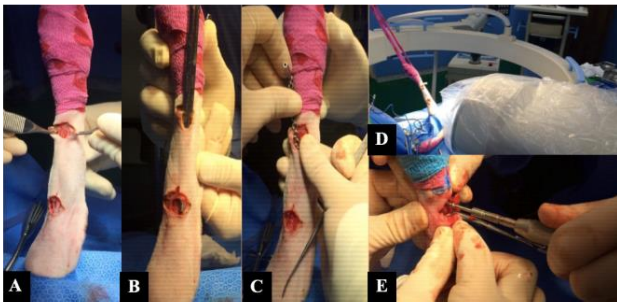

Fig. 2: Surgical procedure of the MIPO technique. (A) Fractured limb in a dependent hanging limb technique. And proximal and distal incisions of 2 to 4 cm. (B) Metzenbaum scissors were used to create an epiperiosteal tunnel for plate insertion. (C) Plate insertion starts at the distal incision along the cranial surface of the radius through the epiperiosteal tunnel. (D) Proper positioning of the bone plate on the radius can be assessed with fluoroscopy. (E) Screws were inserted in the bone plate using a drill bit and drill guide.

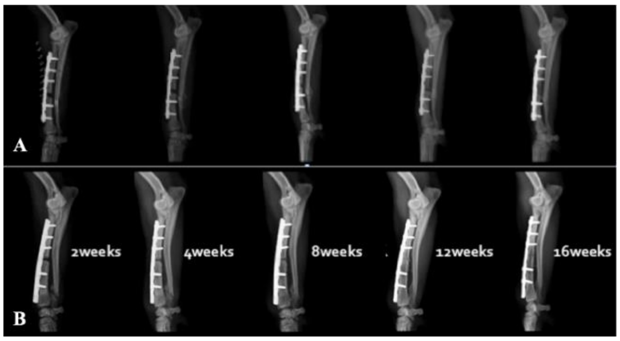

Fig. 3: Radiographs from the (A) Group A received ORIF and (B) Group B received MIPO experimental dogs were taken at 1, 2, 4, 8, 12, and 16 weeks.

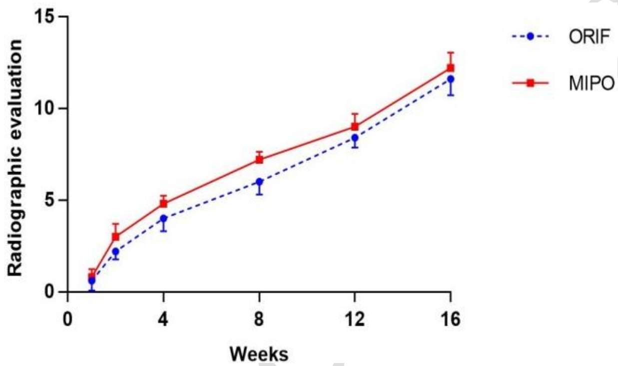

Fig. 4: Radiographic scores among the three groups at 1, 2, 4, 8, 12, and 16 weeks postoperatively.

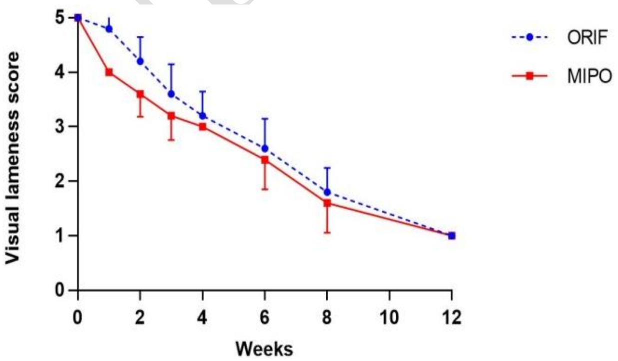

Fig. 5: Gait assessment using modified visual lameness score was recorded at 1, 2, 3, 4, 6, 8, and 12 weeks postoperatively. Group B was less lame than Group A with significance (P<0.05).

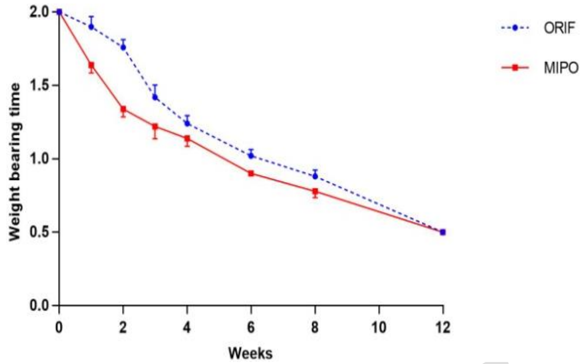

Fig. 6: Weight-bearing time scored at 1, 2, 3, 4, 6, 8, and 12 weeks post operatively. Group B bore a little more weight than Group A with significance, especially in the first 3 weeks after surgery (P<0.05).

Visual lameness score: All dogs were evaluated for visual lameness using 6 grades: 0=no detectable lameness; 1=barely detectable lameness; 2=mild lameness; 3=moderate lameness; 4=severe lameness (intermittent non-weight bearing at trotting); 5=complete lack of use (non-weight bearing at stance, walking, and trotting). In the evaluation scoring after surgery, Group B was less lame than Group A with significance (P<0.05; Fig. 5).

Weight-bearing time: All dogs were evaluated for weight loading using 3 grades: 0=complete weight bearing; 1=partial weight bearing; 2=no weight bearing. This evaluation assessed the time until the dogs began putting weight on the injured limb. Group B bore a little more weight than Group A with significance, especially in the first 3 weeks after surgery (P<0.05; Fig. 6).

Range of motion: The mean ROM of the contralateral carpus was 186.00±12.11° (range 178° to 204°), and that of the elbow was 154.00±11.55° (range 140° to 168°). The percentage of ROM of the affected limb compared to the contralateral limb was recorded at 4, 8, 12, 16 weeks postoperatively (Table 1). There was no significant difference among groups.

Complications: No dogs experienced specific complications in the present study.

DISCUSSION

Bone tissue has unique structural properties; when damaged, it regenerates to its native form rather than healing with repaired tissue (Bigham-Sadegh and Oryan, 2015). The interfragmentary strain conceptualized by Perren *et al*. divides bone regeneration into primary and secondary healing based on differences in the local motion between fragments (Perren, 2002). Primary bone healing involves a direct attempt by the cortex to re-establish itself after interruption without formation of a fracture callus (Perren, 2002). This healing occurs when the bone is rigidly stabilized, such as by fixation with a compression plate, to decrease interfragmentary motion (Marsell and Einhorn, 2011). Such rigid stabilization suppresses the formation of a callus in both cancellous and cortical bone and allows primary bone healing to occur by direct remodeling of lamellar bone, the Haversian canals, and blood vessels (Bighan-Sadegh and

Table 1: Range of motion (ROM) in each dog. The percentage of ROM of the affected limb was compared to that of the contralateral limb at 4, 8, 12, and 16 weeks postoperatively

No.	Group	Fractured bone	Joint	ROM compared with non-affected Limb (%)			
				4 weeks	8 weeks	12 weeks	16 weeks
1	A (ORIF)	Radius	Elbow	71	72	69	72
			Carpus	73	85	92	89
2	A (ORIF)	Radius	Elbow	72	78	83	81
			Carpus	62	61	63	64
3	A (ORIF)	Radius	Elbow	73	77	78	83
			Carpus	81	88	101	104
4	A (ORIF)	Radius	Elbow	91	93	93	100
			Carpus	62	78	87	89
5	A (ORIF)	Radius	Elbow	78	88	90	92
			Carpus	74	79	83	80
6	A (ORIF)	Radius	Elbow	69	78	83	96
			Carpus	81	88	86	92
7	B (MIPO)	Radius	Elbow	87	89	92	94
			Carpus	76	74	75	80
8	B (MIPO)	Radius	Elbow	85	89	92	92
			Carpus	89	91	93	94
9	B (MIPO)	Radius	Elbow	92	94	97	96
			Carpus	93	94	96	100
10	B (MIPO)	Radius	Elbow	84	86	94	96
			Carpus	87	90	93	93

Oryan, 2015). Secondary bone healing is the more common method of bone healing, characterized by spontaneous fracture healing in conditions with limited fragment motion (Marsell and Einhorn, 2011) and involving a response of the periosteum and soft tissues surrounding the fracture site. In this biomechanical environment, new bone is formed following the initial formation of a cartilage template that is progressively replaced by bone via endochondral ossification (Schindeler *et al*., 2008). This differentiation occurs with conditions of cyclic motion and the associated shear stresses at the fracture site and promotes cell proliferation and production of a cartilaginous fracture callus (Oryan *et al*., 2015).

Although it was initially believed that rigid fixation of fractures (and the resultant primary bone formation) was necessary for optimal return to function, recent evidence demonstrates the considerable advantages of secondary bone healing in many long bone fractures, though not for articular surface fractures (Bighan-Sadegh and Oryan, 2015). Also, the treatment of long bone diaphyseal fractures now focuses on preserving the vascular supply to fracture sites as an alternative to anatomic reconstruction and rigid stabilization (Guiot and Déjardin, 2011; Pozzi *et al*., 2013). Iatrogenic damage to soft tissues and the periosteum, along with fracture hematoma, can prolong fracture healing and predispose the area to infection, potentially resulting in delayed union or non-union (Marsell and Einhorn, 2011; Hudson *et al*., 2012; Peirone *et al*., 2012). In response to complications associated with ORIF techniques, a paradigm shift has occurred, and clinicians now focus on reducing iatrogenic trauma and encouraging early callus formation with rapid secondary bone healing. One of the most recent evolutions in biological internal fixation is the MIPO technique, which can reduce iatrogenic soft tissue injury and infection and potentially speed the return to limb function by using indirect reduction. It has produced good clinical outcomes (Hudson *et al*., 2012; Pozzi *et al*., 2013).

The radius was chosen as the fracture gap model for this study; fractures of the radius and ulna are associated with a high incidence of delayed union or non-union (Baltzer *et al*., 2015) because the major diaphyseal arteries enter the radius through the nutrient foramen on its caudal surface in the proximal one-third of the diaphysis (Baltzer *et al*., 2015). Only a few previous studies compared MIPO and ORIF in the radius and ulna in dogs. Pozzi *et al*. compared healing time using ultrasonography and radiography in dogs (Pozzi *et al*., 2012). In that study, fractures in dogs treated with MIPO healed faster and with more callus formation than those treated with ORIF. In another study, callus formation following an ulnar fracture and MIPO or ORIF was compared using micro-computed tomography (CT) and histomorphometry (Xu *et al*., 2015). Similar to those of previous studies, our results suggest that preserving periosteal blood supply could promote early callus formation and mineralization. To the best of our knowledge, this study is the first to compare clinical and functional outcomes following MIPO and ORIF in dogs. We compared the two osteosynthesis techniques using radiographic scoring, visual lameness scoring, weight-bearing time and range of motion.

The radiographs were evaluated using a modification of the scoring system of Patel *et al*. The original radius union scoring system used a 3-point scale (Patel *et al*., 2014), which we expanded to a 5-point scale to assess and compare the process of fracture healing in more detail. In the previous study, radiographs of dog underwent MIPO surgery restored to normal in 4 weeks (Pozzi *et al*., 2013). The present study showed that the MIPO group received slightly better assessments of callus formation than ORIF group at all of points but did not show statistical significance any points. And all dogs in this study were restored to normal radiographs in 16 weeks in both groups.

The visual lameness scoring was evaluated using six grades of lameness severity (Quinn *et al*., 2007), and the weight-bearing scoring used a 3-point scale. Both of these assessments showed similar results: the dogs in the experimental MIPO group were able to bear weight on the affected limb faster than those in the experimental ORIF group. The significance of the difference between experimental groups was low, but the number of dogs in the experimental groups was also low. In the previous study, dogs underwent MIPO surgery healed to normal activity within 4 weeks and dogs underwent ORIF surgery healed in approximately 8 weeks (Pozzi *et al*., 2013). The present study showed that the MIPO group received more significant assessments than ORIF group, especially in the first 3 weeks after surgery. After 12 weeks, both groups recovered to normal activity at the same point in 12 weeks.

The dogs in the MIPO group had better ROM than those in the ORIF group in the early stages of healing, but ROM gradually increased in all dogs over the course of 12 weeks. Possible reason of difference in outcomes between the groups is MIPO group had less soft tissue swelling and postoperative pain than those in the ORIF group.

The results of present study were different from the recovery period of previous MIPO study because it was the experiment using the fracture gap model. Even though all the results showed an extended recovery period than the previous study, we found that the MIPO group recovered little more rapidly than the ORIF group through radiographic evaluation, visual lameness score and weight-bearing time. And in present study, there were no significant intra- or postoperative complications with either procedure. According to reports from human medicine, postoperative complications with MIPO occur rarely and include superficial or deep infection, screw loosening or breakage, implant failure, delayed union, nonunion, and mal-aligned union (Hasenboehler *et al*., 2007; Ronga *et al*., 2010; Buckley *et al*., 2011; Craig *et al*., 2018; Townsend and Lewis, 2018). Several studies have reported the rate of delayed union or non-union to be 5–17% (Hasenboehler *et al*., 2007). Furthermore, the rates of femoral and tibial rotational mal-alignment after MIPO surgery were reported to be 38.5% and 50%, respectively (Buckley *et al*., 2011). We did not observe any rotational mal-alignment after MIPO. We also found more rapid recovery in the early healing stage in the MIPO group than in ORIF group using both clinical and functional assessments.

The major limitation of this study is that the dogs did not natural fracture patients but fracture gap models. The incomplete healing of the soft tissue and periosteum damage is thought to occur because the fracture gap model requires an invasive process with a saw. Nevertheless, the results of present study showed that the MIPO group recovered more rapidly than the ORIF group. Another limitation was the small number of dogs in the experimental groups, which might have affected the significance of the differences in the radiographic scoring, visual lameness and weight-bearing assessments. Future prospective studies should compare the outcomes following MIPO and ORIF in a larger group of dogs to elucidate whether MIPO has a clear clinical advantage over ORIF.

Conclusions: The MIPO technique can reduce damage to soft tissue and the periosteum. We found that early healing was more rapid in the MIPO group than the ORIF group in fracture gap model. Therefore, MIPO offers clinical advantages and better prognosis than ORIF in dogs with radial fractures.

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Authors contribution: MK, YK, HJ performed the surgery and postoperative care. KL, NS and MK held consultation about overall plan of study. YK, HJ and MK wrote the manuscript. All authors read and approved the final manuscript.

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