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Research Article

Clinical and Radiological Evaluation of Tie-in Osteosynthesis with Intramedullary Threaded Pin in Diaphyseal Humeral, Tibial, and Femoral Fractures in Dogs

Uğur AYDIN [1,a (*)] İsa ÖZAYDIN [1,b] Özgür AKSOY [1,c] Celal Şahin ERMUTLU [1,d]
Engin KILIÇ [1,e] Uğur YILDIZ [1,f] Ersin TANRIVERDİ [1,g]

[1] Kafkas University, Faculty of Veterinary Medicine, Department of Surgery, TR-36100 Kars - TÜRKİYE
ORCIDs: [a] 0000-0001-5756-4841; [b] 0000-0003-4652-6377; [c] 0000-0002-4800-6079; [d] 0000-0002-8923-7682; [e] 0000-0001-8126-3918
[f] 0000-0002-4782-1012; [g] 0000-0001-8502-2070

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Abstract: This study aimed to perform the "tie-in" osteosynthesis technique using an intramedullary threaded pin for the treatment of diaphyseal humeral, tibial, and femoral fractures in dogs, thus minimizing rotational movements and strengthening stabilization, particularly in distal diaphyseal fractures. The study included 16 fracture cases involving 14 dogs of various breeds and sexes, aged 3-12 months, and diagnosed with diaphyseal humeral, tibial, and femoral fractures. Depending on the size of the case, Ø2-4 mm-threaded Steinmann pins were preferred for use in intramedullary pinning and Ø2-4 mm-threadless Steinmann pins were placed transversal for fixation. Acrylic, rod, or fiberglass plaster was used to attach the inserted pins. Fusion was formed in all except two cases. Consequently, the animals could use their relevant extremities without issues during the first 3 days following the operation, but from day 3 until day 15, the animals were reluctant to use their relevant extremities. After day 15, the animals could use their extremities without difficulty. The external fixator components used in fracture fixation were entirely removed after 5-7 (mean 6) weeks. In the functional evaluation, the conditions were very good in nine cases, good in four, moderate in one, and poor in two. The results reveal that the use of threaded pins in intramedullary pinning, the first step of the tie-in method, provides good stabilization in fracture treatment, especially in distal diaphyseal fractures.

Keywords: *Diaphyseal fracture, Dog, Femur, Humerus, Tibia, Tie-in osteosynthesis*

Köpeklerde Diyafizer Humerus, Tibia ve Femur Kırıklarında İntramedüller Yivli Pin İle Tie-in Osteosentezin Klinik ve Radyolojik Olarak Değerlendirilmesi

Öz: Bu çalışma ile köpeklerde diyafizer humerus, tibia ve femur kırıklarının sağaltımı için "tie-in" osteosentez tekniğinin intramedüller yivli pin ile gerçekleştirilmesi, bu sayede rotasyonel hareketlerin minimuma indirilmesi, özellikle distal diyafizer kırıklarda stabilizasyonun daha güçlü hale getirilmesi amaçlanmıştır. Diyafizer humerus, tibia ve femur kırığı tanısı konulan, yaşları 3 aylık ile 12 aylık arasında değişen farklı ırk ve cinsiyete sahip 14 köpeğe ait 16 kırık olgusu çalışmaya dahil edildi. Fiksasyonda olgunun büyüklüğüne göre intramedüller pinleme için Ø2-4 mm yivli Steinmann pinler ile transversal olarak yerleştirilecek olan Ø2-4 mm yivsiz Steinmann pinler tercih edildi. Yerleştirilen pinleri birleştirmek için akrilik, rot veya fiberglas alçı kullanıldı. Olguların 2'si hariç tüm olgularda kaynama şekillendi. Olguların tamamında operasyon sonrası ilk 3 gün ilgili ekstremitelerini kullanmada herhangi bir problem olmadığı fakat, 3. günden sonra 15. güne kadar hastaların ilgili ekstremitelerini kullanmada isteksiz olduğu, 15. günden sonra ise hayvanların ekstremitelerini sorunsuz olarak kullandıkları öğrenildi. Kırık fiksasyonunda kullanılan eksternal fiksatör bileşenleri 5-7 (ort. 6) hafta sonra tamamen uzaklaştırıldı. Fonksiyonel değerlendirmede olguların 9'unda çok iyi, 4'ünde iyi, 1'inde orta ve 2'sinde ise zayıf olarak değerlendirildi. Sonuç olarak, kırık sağaltımında iyi bir stabilizasyon sağlayan tie-in yönteminin ilk aşaması olan intramedüller pinlemede yivli pin kullanımının stabilizasyonu güçlendirdiği ve özellikle distal diyafizer kırıklarda iyi bir stabilizasyon sağladığı ortaya konulmuştur.

Anahtar sözcükler: *Diyafizer kırık, Köpek, Femur, Humerus, Tibia, Tie-in osteosentez*

Introduction

Although humeral fractures in dogs are uncommon [1,2], tibial and femoral fractures are frequently encountered [3,4]. Fractures resulting from various traumas occur most frequently following traffic accidents [3]. Implants such as intramedullary pins, bone plates, screws, external fixators, and cerclage wire are widely used to treat long-bone

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(*) Corresponding Author
Tel: +90 474 242 6836/5222, Fax: +90 474 242 6836
E-mail: uguraydin076@hotmail.com (U. Aydın)

fractures [4,5]. Fracture treatment may vary according to factors such as the animals' characteristics, fracture type, lesions associated with the fracture, operator ability, and cost. Thus, the advantages of the chosen technique should be maximized and the disadvantages kept at a minimum [4,6].

Intramedullary pining is the fixation technique most often utilized for treating long-bone fractures. While it is a simple and practical technique, it does have some disadvantages, including pin migration, infection, and an inability to resist the bone's rotational strength. Thus, combining a unilateral external fixator with an intramedullary pin is a widely employed procedure in preventing these complications [7,8].

The "tie-in" technique, which allows the early use of the extremity with good stabilization, is an easy-to-apply minimally invasive technique that causes minimal damage to growth plates and endosteal vascularization owing to the use of intramedullary small diameter pins and is compatible with bone growth and is an easy-to-apply minimally invasive technique that causes minimal damage to growth plates and endosteal vascularization [9]. However, drawbacks have been observed, such as pin migration, rotational movement of bone fragments following intramedullary pinning, which is the first stage of the procedure, and appearance of serosanguineous discharge in the proximal part of the pin as a result of these movements [2,3,9-13].

This study aimed to use an intramedullary threaded pin to conduct the "tie-in" osteosynthesis approach for the treatment of diaphyseal humeral, tibial, and femoral fractures in dogs, reducing rotational motions and improving stabilization, especially in distal diaphyseal fractures.

Material and Methods

Ethical Approval

This study obtained approval from the Animal Experiments Local Ethics Committee of Kafkas University (Approval number: KAÜ-HADYEK/2021-168). In addition, an "informed consent form" was obtained from the owner of each animal.

Case Selection

The study included 16 fracture cases involving 14 dogs of various breeds and sexes, aged 3-12 months, who were brought to the Animal Hospital of the Faculty of Veterinary Medicine of Kafkas University, with the complaint of lameness because of a traffic accident or other traumas and diagnosed with fractures in the diaphyseal humerus, tibia, and femur *(Table 1)*.

Animals that presented with complaints of lameness because of traffic accidents or other traumas were subjected to systematic general examinations. Animals with acute trauma were assessed for bleeding and diaphragm rupture. The fracture was then inspected and palpated. For a definitive diagnosis, mediolateral and craniocaudal radiographs of the affected extremity of each dog were taken. After determining the fracture's anatomical location and shape, it was prepared for operation.

Surgical Equipment

Depending on the size of the case, Ø2-4 mm-threaded Steinmann pins (Safir®, Antalya/Turkey) were preferred for use in intramedullary pinning, and Ø2-4 mm non-threaded Steinmann pins (Safir®, Antalya/Turkey) were placed transversely for fixation. Acrylic, rod, or fiberglass plaster (Optima Cast®, Coin Enterprise Co. Ltd, ABD) was used to attach the inserted pins.

Surgical Procedure

Cefazolin, 30 mg/kg, IM (Cezol, Deva®, Istanbul), was administered to the animals 0.5-1 h before surgery. Following the shaving and cleaning of the relevant extremities, the area was prepared for aseptic surgery. Following sedation with 0.2 mg/kg xylazine HCl (Rompun® 2%, Bayer, Istanbul) intramuscularly and induction with 5 mg/kg ketamine HCl (Ketakontrol®, Doğa İlaç, Istanbul) intravenously, the procedure was performed under inhalation anesthesia with a 2% concentration of isoflurane (Forane, AbbVie®, Istanbul).

To access the fracture site, the lateral approach to the femur, craniolateral approach to the humerus, and medial approach to the tibia were preferred. Following the exposure of the fracture fragments, a threaded Steinman pin with a diameter of 2-4 mm and a length of 25-30 cm was introduced retrogradely into the intramedullary cavity, not exceeding 40%-50% of the bone diameter. After the anatomical bone alignment, 1 or 2 Steinman pins in diameters suitable for the proximal and distal fracture fragments were placed unilaterally (type I) enough to pass the opposing cortex and perpendicular to the long axis of the bone, taking into account the shape of the fracture, anatomical location, and animal's weight. Control radiographs were taken thereafter, and the operation opening was closed using the standard manner. The exterior pin ends were connected with acrylic, rod systems, or fiberglass plaster, considering the weight of the dogs. The pin tips were secured with the chosen fixation material, and the process was completed by securing the pin's root with 10% povidone-iodine *(Fig. 1)*.

Radioulnar fractures were found in two animals with femoral fractures. Apart from the tie-in configuration technique, various fixation methods (plate osteosynthesis) were used to treat the radioulnar fractures.

Table 1. *Preoperative and postoperative results of 14 patients which underwent intramedullary threaded pin tie-in configuration*

Case No	Signalment	Description of the Fracture	Configuration	Concomitant Injury /Treatment	Complications	Functional Outcome
1	5-months-old, Male, Mix Breed, 8 kg	Diaphyseal, oblique, femoral fracture	1 IM threaded pin (2 mm), 1 (PF) (2 mm), 1 (DF) (2 mm)	None	None	Excellent
2	3.5-months-old, Male, Mix breed, 6 kg	Diaphyseal, oblique, humeral fracture	1 IM threaded pin (2 mm), 1 (PF) (2 mm), 1 (DF) (2 mm)	Radial paralysis/Recovered after osteocentesis	None	Excellent
3	3-months-old, Female, Mix breed, 8 kg	Diaphyseal, transversal, bilateral, femoral fracture	1 IM threaded pin (2 mm), 2 (PF) (2 mm), 1 (DF) (2 mm)	None	None	Excellent/Good
4	4.5-months-old, Male, Mix breed, 7 kg	Diaphyseal, transversal, femoral fracture	1 IM threaded pin (2 mm), 1 (PF) (2 mm), 1 (DF) (2 mm)	None	None	Excellent
5	12-months-old, Male, Mix breed, 25 kg	Diaphyseal, oblique, femoral fracture	1 IM threaded pin (3 mm), 2 (PF) (3 mm), 2 (DF) (3 mm)	None	Transversal pin migration	Poor
6	3-months-old, Male, Mix breed, 6 kg	Diaphyseal, oblique, femoral fracture	1 IM threaded pin (3 mm), 2 (PF) (2 mm), 2 (DF) (2 mm)	None	None	Excellent
7	5-months-old, Male, Mix breed, 16 kg	Diaphyseal, transversal, tibial fracture	1 IM threaded pin (3 mm), 1 (PF) (3 mm), 2 (DF) (3 mm)	Radius-Ulna Fracture/ Plate osteosynthesis	Hypertrophic callus	Fair
8	6-months-old, Male, Turkish shepherd dog, 20 kg	Diaphyseal, transversal, femoral fracture	1 IM threaded pin (4 mm), 2 (PF) (3 mm), 2 (DF) (3 mm)	Radius-Ulna Fracture/ Plate osteosynthesis	None	Good
9	8.5-months-old, Male, Mix breed, 15 kg	Distal diaphyseal, transversal, tibial fracture	1 IM threaded pin (3 mm), 2 (PF) (2 mm), 1 (DF) (3 mm)	None	None	Excellent
10	5-months-old, Male, Zerdava,12 kg	Diaphyseal, oblique, humeral fracture	1 IM threaded pin (3 mm), 1 (PF) (3 mm), 2 (DF) (2 mm)	None	None	Excellent
11	5.5-months-old, Female, Kangal dog,24 kg	Diaphyseal, segmental, femoral fracture	1 IM threaded pin (4 mm), 2 (PF) (4 mm), 2 (DF) (3 mm)	None	Transversal pin migration	Poor
12	9-months-old, Female, Kangal dog, 33 kg	Diaphyseal, oblique, tibial fracture	1 IM threaded pin (4 mm), 2 (PF) (4 mm), 2 (DF) (4 mm)	None	None	Good
13	8-months-old, Male, Mix Breed, 32 kg	Diaphyseal, oblique, humeral fracture	1 IM threaded pin (4 mm), 2 (PF) (4 mm), 2 (DF) (3 mm)	None	None	Excellent
14	11-months-old, Female, Kangal dog, 34 kg	Diaphyseal, oblique, bilateral femoral fracture	Right femur: 1 IM threaded pin (4 mm), 2 (PF) (3 mm), 1 (DF) (3 mm), Left femur: 1 IM threaded pin (4 mm), 1 (PF) (3 mm), 2 (DF) (3 mm)	None	None	Excellent/Good

PF: *Proksimal fragment,* ***DF:*** *Distal fragment,* ***IM:*** *Intramedullary*

Fig 1. Fixation of postoperative "tie-in" external fixator components

Postoperative Care and Follow-up of Cases

Animals were admitted to the hospital for 48-72 h and received daily antibiotic treatment, pain management, and postoperative care. The animals' owners were informed about keeping the animals in a narrow area before discharge and daily cleaning of the pin bottoms with povidone-iodine (10%). In addition, antibiotics (cefazolin, 30 mg/kg, IM, Deva, Istanbul) were administered for 7 days and meloxicam (0.2 mg/kg/day, SC, Bavet Meloxicam, Bavet®, Istanbul) for 3 days for pain control. Clinical and radiological evaluations were made for control at intervals of 2 or 3 weeks postoperatively.

Taking into mind the healing tables, the pins were totally removed after 5-7 (average 6) weeks.

According to Yardımcı et al.[3], recovery was graded based on relative measurements such as the animal's readiness to use the operated limb, degree of weight-bearing, and presence of resistance to flexion/extension of the shoulder, elbow, hip, and knee joints. Accordingly, the findings were marked as excellent (no visible lameness, full weight bearing, functional use of the operated limb, and no

palpable pain), good (obvious full weight bearing, no obvious lameness during gait but mild lameness following strenuous exercise, and no palpable pain), moderate (marked lameness but consistent weight bearing, and apparent resistance to flexion and extension), and weak (no limb use, non-weight-bearing lameness, resistance, and pain in flexion and extension). The last clinical evaluation was conducted for control within 1-2 months after pin removal. All evaluations were completed by an academic who was not a member of the research team.

Results

In this study, the dogs were 3-12 months old (6.36±2.89 months). Femoral fractures were found in eight of the animals (unilateral in 6 cases and bilateral in 2), humeral fractures in 3, and tibial fractures in 3 *(Table 1)*. Acrylic plaster for dogs weighing <20 kg (n = 8), rod system for dogs weighing 20-30 kg (n = 3), and fiberglass plaster for dogs weighing >30 kg (n = 3) gave sufficient stabilization in pin fixation to join the outside pin ends, without any complications. In only one case, the owner reported that the animal broke the acrylic on postoperative day 2 (case 4). The animal was immediately brought to the clinic, and the fixation procedure was renewed with fiberglass plaster. In all cases, the use of the relevant extremities was not difficult in the first 3 days after the operation. However, from days 3-15, the animals were cautious to use their respective extremities when pressing the ground, either reluctantly or not at all, and after day 15, the animals used their extremities without any difficulty. The recovery of animals with humeral fractures (n = 3) was uneventful and without any complications. One of these animals (case 2) had radial paralysis in addition to the fracture in clinical examination. In this case, the paralysis resolved spontaneously during the fracture healing process, and the animal exhibited a normal gait. It was learned from the owner that no clinical problem occurred in this case until day 15, while 2 of 3 cases with tibial fractures were fully healed. However, when X-ray images were taken on days 21 and 35, a hypertrophic callus had formed on the fracture line *(Fig. 2)*. When the owner was asked whether they followed the recommendations for confinement, they permitted the animal to move freely because it has no walking difficulties. Despite the formation of overflow callus, the animal could use the relevant extremity with ease. Moreover, 6 of the 8 dogs with femoral fractures (6 unilateral and 2 bilateral fractures) had an uncomplicated recovery, while in two dogs (cases 5 and 11,) a complete recovery was not achieved because the owners were following the confinement recommendations, which results in the protrusion of the transversal pins. The external fixator was removed, and stabilization was accomplished with the plate in these two dogs that could not fully heal.

Fig 2. Radiograph on postoperative day 35 of case 7. Hypertrophic callus formed in the tibia

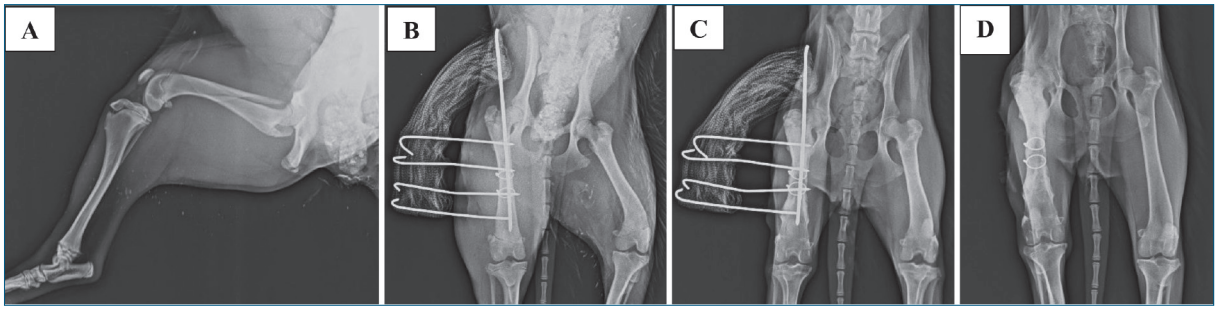

Fig 3. A- Preoperative radiograph of a diaphyseal long oblique femoral fracture, **B**- Immediate postoperative radiograph, **C**- Radiograph on postoperative day 35, **D**- Radiograph on postoperative day 40

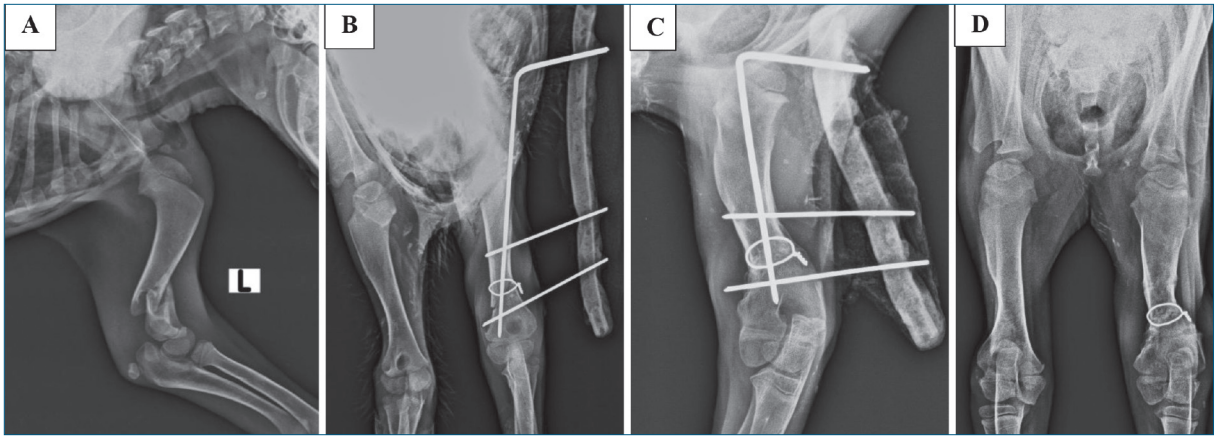

Fig 4. A- Preoperative radiograph of a case of distal diaphyseal short oblique humeral fracture, **B**- Immediate postoperative radiograph, **C**- Radiograph on postoperative day 35, **D**- Radiograph on day 35 after the removal of the postoperative tie-in components

Table 1 summarizes the clinical findings and recovery status of the cases.

In many cases, seroma formation at the entrance of the intramedullary pin was noted to be limited or insignificant. No major pin infection was observed in the transversally placed pins. Except for three cases that developed complications, all other cases healed without issues *(Fig. 3, Fig. 4)*. Following the pin removal, the owners were followed up for 1-2 months to obtain information about the condition of the animals, and they did not have any complaints.

Discussion

Although femoral and tibial fractures are prevalent, especially in dogs in the developmental period [9,13,14], humeral fractures are the least common long-bone fractures [1]. The majority of fractures occur following trauma sustained in traffic accidents. Especially, in animals brought due to a complaint of trauma-related fractures, conditions such as nerve damage, internal bleeding, rupture of the diaphragm, and fractures in more than one bone may occur [1,2]. In this study, the fractures occurred in dogs aged <12 months. This may be related to the fact that animals are in a more active stage of their lives and in the early phases of bone development. Although various traumas effectively result in fractures, fractures in the majority of our cases were formed following traffic accidents. Given the extent to which the body is damaged in motor vehicle accidents, lesion formation in more than one bone is possible. While bilateral femoral fractures were observed in two of the cases, one involved an ipsilateral radioulnar fracture in tandem with a tibial fracture and another involved a femoral fracture. Radial paralysis was observed in the clinical examination of only one animal with a humeral fracture, but no signs of paralysis were found following the operation. One could argue that paralysis occurs as a result of the pressure exerted by fracture fragments, which subsides with fracture fixation.

Many fixation methods are used in the treatment of humeral, femoral, and tibial fractures, including Thomas splint, bandage, intramedullary pin, plate osteosynthesis, and external fixator components [2,15-18]. However, each of these strategies has several advantages and disadvantages over one another. Because closed reduction is not possible due to the strong muscles around the femur and humerus, closed reduction (bandage, etc.) is not very suitable for fractures of these bones [1,3]. Intramedullary pining is the most commonly used fixation technique for the treatment of long-bone fractures. Although it is a simple and practical technique, it has many disadvantages, such as pin migration, infection, and inability to resist the rotational force of the bone [7,8]. To avoid these problems, fixation with plates is more preferred today [1,19]. However, one of the disadvantages of bone plates is that they must be removed by an invasive surgical operation [4,19]. Although external fixator systems (semicircular-circular) provide adequate stabilization in fracture treatment, the unsuitable anatomical structure of the relevant regions prevents their use in fractures of these bones, especially in the approach to humeral and femoral fractures. As a result, a unilateral (type I) exoskeleton fixator is an easy approach to the fracture, minimally invasive, easily intervenable in emergencies, does not require an operation to remove it from the implanted bone after healing, can resist rotational forces, and is an intramedullary pin [3,7,9,13]. After weighing the advantages and disadvantages of each fixation method, our study determined that the tie-in method, which has some advantages in humeral, femoral, and tibial fractures, was preferred. In our study, a threaded pin was used in intramedullary pinning, the first step of the tie-in method; thus, the fragment rotation that may result from the pin was neutralized.

Intramedullary and externally implanted pins are commonly

combined using acrylic or metallic rod and a rod system consisting of connection clips when employing the tie-in configuration technique [4,8,20]. However, clip loosening, shape of the intramedullary pin, and migration have been reported as problems resulting in the loss of stability [4,12,20]. In our investigation, fiberglass plaster was employed to combine intramedullary and externally implanted pins in addition to acrylic and rod systems. One of the animals shattered the acrylic, and no further complications were found. The animal has a nervous temperament, and stress factors have a role in this situation. Although a few issues were associated with the fixation apparatus, the most appropriate equipment should be chosen based on the animal's movement, temperament, and weight during the joining process. According to our experience, fiberglass plaster provides good stabilization among the materials used for joining pins because of its low cost and mechanical strength that can withstand excessive stress, especially in large animals. On the contrary, acrylic is a better choice for small animals, as a lighter material.

In fracture fixation, the tie-in method has several advantages over alternative methods. The interlocking of the connection apparatus and pins is the most essential characteristic of this system, as it prevents the loosening and migration of the transversal and intramedullary pins [9]. However, difficulties have been documented in several investigations, particularly in intramedullary pin migration and discharge at the proximal ends of the intramedullary pin [2-4,12,21]. In this investigation, no loosening, pin migration, or a significant infection that could be precipitated by these issues were observed in any of the cases because the intramedullary pin is threaded, unlike the traditional tie-in procedure. However, in many animals, this investigation showed limited or insignificant seroma production at the pin insertion site, as reported by all investigators. Furthermore, the intramedullary threaded pins used have screw quality and provide greater stabilization in distal diaphyseal or proximal diaphyseal fractures. As the diameter of the intramedullary pin in the tie-in method should not be more than 40%-50% of the bone diameter, it is reasonable to conclude that the use of threaded pins will eliminate many issues and contribute significantly to the advancement of the tie-in system.

The primary purpose of fracture fixation is to promote rapid bone healing and early postoperative ambulation to encourage the animals to use functional extremities [2]. The animals did not have any difficulty using the relevant extremities in the first 3 days after the surgeries are performed using the tie-in technique, and they could easily perform their usual activities [2,3]. In our study, the animals could use their respective extremities within the first 3 days after surgery. However, after day 3, some of the animals were not using the relevant extremity and were hesitant to bear weight. After postoperative day 15, they were able to use their extremities without difficulty. During this time, the animals were monitored to observe the occurrence of muscular function loss, and no complications were found. Because of the medicines given for the first 3 days, we can claim that the animals could utilize their extremities with ease. Furthermore, in this scenario, pain stimulation by the influence of numerous mediators in the biological process in the early phases of soft tissue and fracture repair is also effective.

After appropriate stabilization, careful care (particularly at the root of the pin) and feeding, and restriction of motions, fracture healing is usually completed within 28-35 days at the earliest. However, animal size, fractured bone, fracture shape, and other factors can influence the duration of fracture healing [4,13]. According to McCartney et al.[13], the apparatus should be removed between 6 and 8 weeks in animals aged <1 year and between 8 and 10 weeks in animals aged >1 year. Popkov et al.[5] used Ilizarov ESF and intramedullary pins in dogs with experimental fractures and closed growth plates aged 1-5 years, and they found that on postoperative day 28, all fractures were entirely consolidated. Excessive mobility and restriction recommendations in young animals during the recovery phase can result in complications such as transversal pin migration, overflow callus, and late union [2,4]. In our study, the connecting devices were removed after an average of 5-7 (mean 6) weeks. In the cases, no evidence of substantial pin-to-bottom infection occurred. One animal with a tibial fracture had hypertrophic callus, while two animals with femoral fractures experienced transversal pin migration. Excessive straining of the muscles in the fracture area during movement produces aberrant callus production, which is a well-known condition in dogs. According to the experts, the inability to follow the motion restriction rules and excessive activity are the key factors in these cases.

Many treatment options are available for long-bone fractures in dogs. However, it may not be always clear as to which option the operator will implement. Factors such as the anatomical location of the fractured bone, fracture shape, animal weight, physician skill, and cost are effective in determining the appropriate technique. Therefore, obviously, the low-cost minimally invasive tie-in configuration technique, which is an easy approach to fractures, can be adapted to any fracture shape, puts equal load on the fracture line, prevents rotation, and is extremely useful.

In this study on the fixation of long-bone fractures in dogs, the tie-in configuration technique using intramedullary threaded pins had a lower complication rate and clinically satisfactory results.

Availability of Data and Materials

The datasets analyzed during the current study are available from the corresponding author (U. Aydın) on reasonable request.

Ethical Approval

This study obtained approval from the Animal Experiments Local Ethics Committee of Kafkas University (Approval number: KAÜ-HADYEK/2021-168). In addition, an "informed consent form" was obtained from the owner of each animal.

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Conflict of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of paper.

Author Contributions

UA, İÖ, and ÖA conceived and supervised the study. UA, İÖ, ÖA, CŞE, EK, UY, and ET collected and analyzed data. UA, UY, and ET performed the operation and radiographic examinations. All authors contributed to the critical revision of the manuscript and have read and approved the final version.

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