Evaluation of distal femur fractures in cats by hybrid external fixator

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ABSTRACT

In this study, clinical and radiological findings obtained from the treatment of distal femur fractures in cats with hybrid external fixator were evaluated. A total of 10 cats of different ages, breeds and genders with clinically diagnosed femur fractures were used as research material. In the study, hybrid external fixators consisting of circular and linear fixators were used as osteosynthesis material. Closed reduction and external fixation methods were used in 2 cases diagnosed with closed fractures, while limited open reduction and external fixation methods were used in 8 cases diagnosed with open fractures or excessive dislocations. In the radiological examination findings, it was determined that fracture consolidation started on the post-operative 7th day in 9 cases and on the 10th day in 1 case, respectively. Fracture healing was completed in 4 weeks in 2 cases, in 5 weeks in 2 cases, and in 6 weeks in 6 cases (osseous callus was detected). Fixators were removed one week after healing was completed in all patients. In the study, soft tissue complications such as edema in the extremities in 3 cases, mild pin infection in 3 cases and open wounds in 4 cases were determined. However, it was observed that these complications did not adversely affect the recovery time. As a result, with the data obtained from the study, it was concluded that the distal femur fractures in cats of the age and weight scales examined in the study can be successfully treated with the hybrid external fixator system.

Introduction

It is known that femoral fractures of cats are caused by falls from heights, traffic accidents, firearm injuries, fight with other stray animals and human blows (13, 31) Femoral fractures may occur as open, closed, comminuted or segmental. Long-bone fractures constitute approximately 50% of the fracture cases observed in cats, as well as 60% of these fractures are comprised of femoral fractures (13). In addition to this distal femoral fractures comprise 20-30% of all femoral fractures in cats (40).

The treatment of fractures should essentially aims to regain previous anatomic shape of the bone, to improve the functions of traumatized soft tissues and to enable the animal to walk. It has been also emphasized that selected fixation technique should be minimally invasive and easy-applicable (24). In this direction, orthopedic operations should be applied in the treatment of distal femur fractures in order to ensure the normal movement of the joint and to maintain the development of the physis (1, 31, 38).

Single and multiple intramedullary pins, modified Rush pins, cross pins and stiffening wires are used to achieve stability of the fracture fragment (3, 40). Furthermore, small contoured plates, cancellous bone screws and external fixators are the other choices of fixation methods (1, 29, 31). However, the rate of major complications is extremely high in the application of non-rigid stabilization methods such as intramedullary pins (41). In addition, the small fragments in distal femur fractures limit the use of pins or plates, and immobilization of the fracture line can not be achieved adequately (28, 33). Significant complications such as prevention of skin closure, early implant failure, loss of joint range of motion and new bone fractures are encountered in plaque applications (19).

The stabilization obtained using external fixators provides a resistant fixation against shearing, nudging, distraction, compression as well as rotational and torsional forces (11). External fixators are the effective systems that are easily applied in the treatment of various fracture types detected in the patients with different alive weights and sizes (12). Also, Infected wounds with regional material losses, comminuted fractures, open infected fractures preclude achievement of reduction and desired stability and such cases can be treated utilizing external fixator systems (11, 21, 33). These systems are classified in 4 groups as linear external fixators, circular external fixators, hybrid external fixators and computed-assisted external fixators (30).

Biomechanically, circular external fixators have advantages over linear external fixators in terms of stability and rigidity (14, 17, 32). However, the anatomical structure of the femur in cats is not suitable for the application of circular external fixator. For this reason, hybrid external fixator systems consisting of a combination of linear and circular systems are preferred in pet animals, especially in distal femur fractures (17). Thus, circular fixators can be fixed with tensioned k-wires and thus allow micro-movement to shorten the healing time of the fracture (30), while linear fixators can be applied to circular external fixators, one-way to the bone with simple assembly (17).

In this study, it was aimed to evaluate the clinical and radiological findings of treatment of distal femoral fractures by using hybrid external fixators that consisted of circular and linear external fixators in cats.

Materials and Methods

Inclusion Criteria: This study included 10 cats with different breeds, ages and genders and the complaint of severe lameness diagnosed with femoral fracture according to clinical and radiographical examinations without any other systemic disease.

Preoperative Management: The general examination was performed preoperatively and blood parameters were tested (Mindray Bc-2800 Vet, Hasvet, Antalya, Türkiye) in the patients. The patients were administered prophylactic parenteral antibiotic [20 mg/kg ceftriaxone (Unacefin® 0.5 g, Yavuz ILAC, Istanbul, Türkiye)] until the operation. The patients were kept under cage resting until the operation. All the patients were taken to operation within 1-4 days.

In the study, hybrid external fixators designed by Tasarım-Med® Company as the osteosynthesis materials were used. The circular fixator of the hybrid system is composed of half and 5/8 rings in diameter of 50-70 mm made of carbon-fiber alloy with varying number of holes. Linear fixator part of the hybrid system was also constituted by the finger fixator with a capacity of sending at least 4 Schanz pins allowing unilateral pin fixation. Beside these, screws (6 mm) and nuts (6 mm) were used together with 1-1.5 mm Kirschner wire, 2.5 mm Schanz pin, pin tensioner, projections, electric drill, wrenches, soft tissue and orthopaedic sets.

The locations and shapes of the fractures were determined according to preoperative radiographic images of the cases included in the study. Accordingly, hybrid fixator system (frame) was established by determining ring levels and pin-delivery sites.

Retrieved Data: Study data involves fracture etiology, fracture configuration, time from trauma to surgical intervention, findings of physical examination (including neurological examination), surgical technique (including used implants), postoperative complications, time elapsed to fracture healing and time elapsed to removal of the implant.

Surgical Technique: After shaving and disinfection of the fracture site, anaesthetic induction of the patient was achieved by administration of 2 mg/kg intramuscular xylazine HCL (Alfazyne® %2, Egevet, Türkiye) and 10 mg/kg ketamine HCL (Alfamine® %10, Egevet, Türkiye). Maintenance of anaesthesia was performed by administration of 2% sevoflurane (Sevorane®, Abbott, Italy) using closed-circuit anaesthesia device (SMS 2000 Klasik Vent-V, SMS Medical Device, Limited Corporation, Ankara, Türkiye).

The patients were placed in the lateral recumbency on the operating table to place the related extremity on the top. Depending on the status of the fractures; two different techniques were applied as closed reduction external fixation (Cases 1 and 8) and limited incision open reduction external fixation (Cases 2-7, 9 and 10) (Table 1).

Closed Reduction and External Fixation Methods: This method was applied in the cases (Cases 1 and 8) that were diagnosed with closed fracture and that had no excessive dislocation. Traction method was applied to the related extremities of the patients. After achievement of reduction, hybrid system was placed on the related extremity. Kirschner pin was inserted from the closest point to the knee joint on the distal fragment toward caudomedial direction through craniolateral aspect operating the lowest speed of drill. The pin was fixated to the ring using pin-holders and tensioned. Following, linear part of the system was fixated to the bone with 1 piece of Schanz pin at the closest point to coxa-femoral joint and reduction was controlled by radiography. Then, one more Kirschner pin was inserted to the ring from cranio-medial aspect toward cauda-lateral direction by making at least 60° angle with the initially inserted Kirschner pin. The linear

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Table 1. Operation methods applied in fracture cases.

Apenndix table 1 Case No	Operation Technique	Surgery Time (h)	Configuration ring number/ diameter	Fixation Elements on ring
1	CREF	2.30	70 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
2	LİOREF	1.35	70 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
3	LİOREF	2.00	50 mm	2x1.0 mm Kirschner wire 6x2.5 mm Schanz wire
4	LİOREF	1.05	50 mm	1x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
5	LİOREF	1.15	50 mm	1x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
6	LİOREF	1.35	70 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
7	LİOREF	1.50	50 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
8	CREF	1.35	50 mm	1x1.0 mm Kirschner wire 6x2.5 mm Schanz wire
9	LİOREF	1.30	50 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire
10	LİOREF	1.30	70 mm	2x1.0 mm Kirschner wire 5x2.5 mm Schanz wire

LİOREF: limited incision Open Reduction External Fixation,
CREF: Closed Reduction External Fixation

part of the system was fixated using 3 more Schanz pins and the operation was finalized. The cortical perforation procedure by all Kirschner pins was initiated after pushing the pin until the bone using hands. To prevent necrosis and releasing that may occur during perforation procedure; the pin was supported by holding it with a gauze bandage soaked with mixture solution of alcohol and antibiotic.

Limited Open Reduction and External Fixation Methods: This method was applied in the cases (Cases 2-7, 9 and 10) that were diagnosed with open fracture or those with excessive dislocation despite closed state of the fracture. The fragments of the fracture were reached with a limited incision (approximately 3 cm) in the lateral region of the femur and just over the fracture line. The reduction of the fracture fragments was performed using a thin intramedullary pin (a K pin with a diameter of 1-2 mm) that covers one third of medullary canal via retrograde route. Intramedullary pin was kept in the medullary canal until the hybrid system was inserted into the bone. Intramedullary pin was removed after insertion of the hybrid system into the extremity as described for the closed reduction system. The operation was finalized after the appropriate corrections were made.

Postoperative Care: Detailed clinical examination was performed to control whether vascular and muscular structures were active. The patients were administered broad spectrum antibiotics [20 mg/kg ceftriaxone (Unacefin® 0.5 g, Yavuz ILAC, Istanbul, Türkiye), 15mg/kg metronidazole (Flagly 500 mg/100 ml, Sanofi Aventis, Istanbul, Türkiye), 20 mg/kg 5% enrofloxacin (Baytril, 100 mg, Bayer, Istanbul, Türkiye)] alone and in combination regarding postoperative blood count (leukocyte count). Besides, 0.4 mg/kg tolfenamic acid (Tolfine, Novakim, Gebze, Kocaeli, Türkiye) was administered to reduce pain and inflammation. In the cases, pin bases were cleansed using 0.1% rivanol antiseptic solution twice a day for the first 5 days. After 5th day, pin bases were cleansed once daily using 10% povidone iodine (Povidone®, Kimpa, Istanbul, Türkiye). On the other side, pin-base care was performed twice daily in the cases detected with pin-base infection. All the cases were hospitalized for proper postoperative care until completion of fracture healing and removal of fixator.

In the postoperative period; the first radiological examination was carried out on the postoperative 1st day in all the cases. Thereafter, radiological examinations were routinely repeated every week until removal of the fixators. CR Fuji roentgen system (Portable X-Ray Epx-3200, Fujifilm FCR Prima T2, Hasvet, Antalya, Türkiye) was used for radiological examination. One more week was waited in the cases with completed fracture consolidation to loose pin-holders under sedation and fixator was removed by cutting pins.

Clinical outcome assessment: The radiological examination of the patients was performed with an interval of 7 days in the postoperative period and the patients were evaluated regarding continuity of anatomical position, development of a new fracture at the levels of pin insertion and level of fracture healing. The criteria such as use of extremity, the presence of pain and edema, joint functionality and the presence of regional muscular and tendon contractures were reviewed in the clinical control examinations. The findings of the cases were graded according to functional and esthetic grading described by Rovesti (2007) (Table 2).

Results

Of the cases included in the study, 8 were hybrid breeds and 2 were Turkish Van cats, whereas the ages of the cats ranged between 3-5 years (2.7 years) and alive weights were also measured to be between 2-6 kg (4.17 kg). In 10 cases involved in the study, fracture occurred due to traffic accident, trauma and attack by a stray dog in 5, 3 and 2 cases, respectively, and femoral fractures were localized at the distal diaphysis in all the cases. It was determined considering infection and necrotic state in the soft tissue that 6 cases had closed fractures while open and non-infected fractures were found in 4 cases (Table 3).

Table 2. Functional and esthetic grading of the cases in the postoperative period (Rovesti, 2007).

Grade	Lameness Status	Appearance of Extremity
Excellent	Gait is normal, no lameness or pain	Normal appearance
Good	Gait is normal, mild lameness in the extremity	Normal appearance
Moderate	Mild or moderate lameness	Appearance is not excellent
Weak	Extremity is occasionally used, permanent lameness	Abnormal appearance

Table 3. Signalment, Aetiology, Tissue Condition, Fracture Location, Complicatio and outcome veterinary assessment of case.

Case	Signalment* (age, sex, bodyweight)	Aetiology	Tissue Condition	Fracture Location	Complications	first time to use the limb	Completion of Consolidation (day)	Time to fixation removal (day)	Outcome veterinary assessment
1	2-years old Female crossbred 5.3 kg	Traffic Accident	Closed	L-Distal 1/3 diaphyseal transversal	Edema	2	42	49	Excellent
2	5-years old Male crossbred 5.8 kg	Traffic Accident	Closed	L- Distal diaphyseal transversal	soft tissue infections	1	28	35	Good
3	3-years old Male van 5.5 kg	Trauma	Open	R- Distal diaphyseal Oblique	soft tissue infections/ Recurrent Fracture	2	42	42	Good
4	1-years old Female crossbred 2.6 kg	Dog attack	Closed	L- Distal diaphyseal transversal	NO	1	28	35	Excellent
5	3-years old Female crossbred 4.6 kg	Traffic Accident	Closed	L- Distal diaphyseal Oblique	Reduction Deterioration	1	35	42	Excellent
6	3-years old Male crossbred 5.4 kg	Dog attack	Open	R- Distal diaphyseal transversal	Edema	2	42	49	Good
7	2-years old Female crossbred 3.6 kg	Traffic Accident	Closed	L- Distal diaphyseal Oblique	soft tissue infection	2	35	49	Excellent
8	3-years old Female crossbred 4.1 kg	Trauma	Open	R-ant Distal diaphyseal transversal	NO	2	42	49	Excellent
9	2-years old Male van 2 kg	Trauma	Open	L-mt Distal diaphyseal transversal	NO	2	42	49	Good
10	3-years old Female crossbred 2.8 kg	Traffic Accident	Closed	R- Distal diaphyseal transversal	NO	2	42	49	Excellent

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The radiological examination performed at the postoperative 1st week revealed a slight shift on the fracture line in 1 case (Case 5). No procedure was performed in that mentioned case since the fracture fragments contacted to each other by about 90%. However, formation of a new fracture was detected just beneath the former fracture line due to the excessive mobility of the patient and these cases were re-operated. No complication related with reduction was encountered in the other 8 cases according to the radiological results.

Fracture consolidation started on the postoperative 7th day in most of the cases, whereas it observed in 1 case (Case 3) on the 10th day. The radiological examination in the second week revealed that impairing reduction encountered in the 5th case on the first week did not progress. Refracture developing in the 3rd case was operated again and reduction procedure was carried out. The complication was resolved by addition of 1 piece of Schanz pin to the ring in the distal fragment in the operation. It was monitored that healing process of the patient was not negatively affected by this complication and that radiological improvement was similar with the other cases. Besides, no periosteal reaction was radiologically detected on the entrance points of the pin although mild pin-base infections developed in 3 cases (Cases 2, 3 and 6) after the first week (Table 3).

It was determined that fracture line almost disappeared after the third week in most of the cases and that consolidation was nearly completed. It was determined that consolidations were completed within a period ranging between 4-6 weeks (37.8 day) in the fracture line. It was found that secondary fracture recovery occurred in all the cases. The fixators in all cases were removed 1 week after completion of the consolidation of fixator (Figs. 1-4) (Table 3).

Postoperative daily clinical examinations revealed that all the patients tolerated fixators very well. Edema was found in only 3 cases (Cases 1, 6 and 7) on the postoperative 1st day. This condition was detected to be regressed in the 2nd-3rd days. It was determined that all the cases could apply their weight on the related extremities on the postoperative 1st -2nd days (Fig. 5). Lameness degree was observed to be mild and moderate in 6 (Cases 1, 4, 5, 7, 8 and 10) and 4 (Cases 2, 3, 6 and 9) cases, respectively. It was noted that the signs of lameness disappeared in almost all the cases beginning from the postoperative 7th day and the patients could use their extremities functionally. Pin-base infection and subsequent soft tissue infection developed in 3 cases (Cases 2, 3 and 6). However, the infection was eliminated by increasing the number of daily pin-base care. (Pin bases were cleansed using 0.1% rivanol antiseptic solution forth times in a day) Open wound developed in 4 cases (Cases 1, 2, 3 and 6) at the level of femoral lateral condyle after the operation. These cases were applied dressing with rivanol solution three times a day along 3 days. In the following days, dressing was continued with mixture of *Centella asiatica* (Madecassol®, Bayer, Topkapı, Istanbul, Türkiye), nitrofurazone (Furacin®, Zentiva, Inc., Prague, Czech Republic) and rifamycin sodium (Rif®, Koçak Farma, Üsküdar, Istanbul, Türkiye). The wounds were found to be recovered within a period ranging between 13-21 days.

During the study, no complication such as broken ring, broken pin or loosened nut was determined. A slight inclination was detected in Schanz pin in 1 case (Case 3). However, no intervention was carried out since no impairment developed in the reduction. No abnormal looseness was identified in the clinical examination after removal of the fixator in the cases and this evidence was confirmed also with radiological examination.

The patients were hospitalized for one more week after removal of the pins for treatment of the developing lesions and clinical follow-up. This follow-up process indicated that general condition of the patients was good and that none of them has any finding related with lameness (Fig. 6).

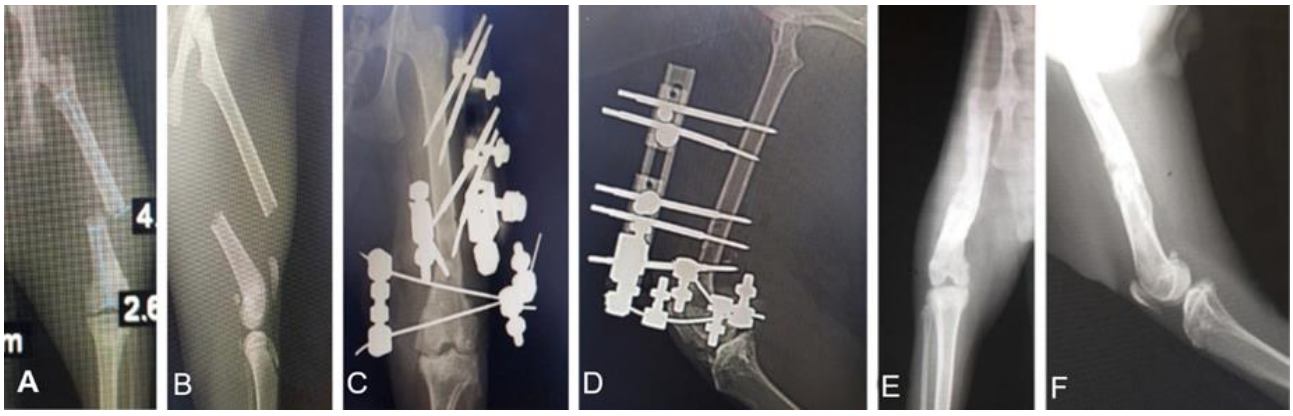

Figure 1. Case no. 2: X-ray images: (A) pre-operative A/P, (B) pre-operative M/L, (C) post-operative day 1 A/P, D) post-operative day 1 M/L (E) after the removal of fixator A/P, (F) after the removal of fixator M/L.

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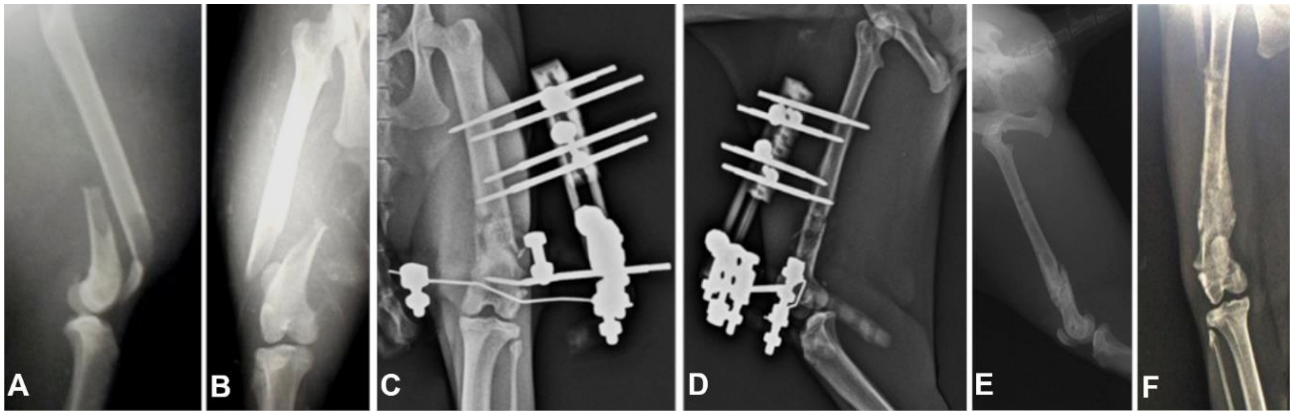

Figure 2. Case no. 5: X-ray images: (A) pre-operative M/L, (B) pre-operative A/P, (C) post-operative day 1 A/P, D) post-operative day 1 M/L (E) after the removal of fixator M/L, (F) after the removal of fixator A/P.

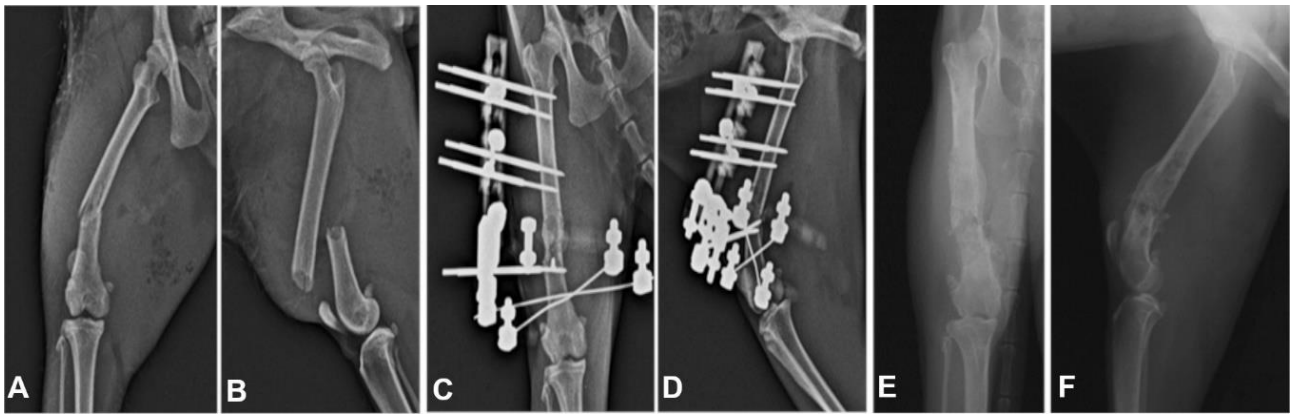

Figure 3. Case no. 6: X-ray images: (A) pre-operative A/P, (B) pre-operative M/L, (C) post-operative day 1 A/P, D) post-operative day 1 M/L (E) after the removal of fixator A/P, (F) after the removal of fixator M/L.

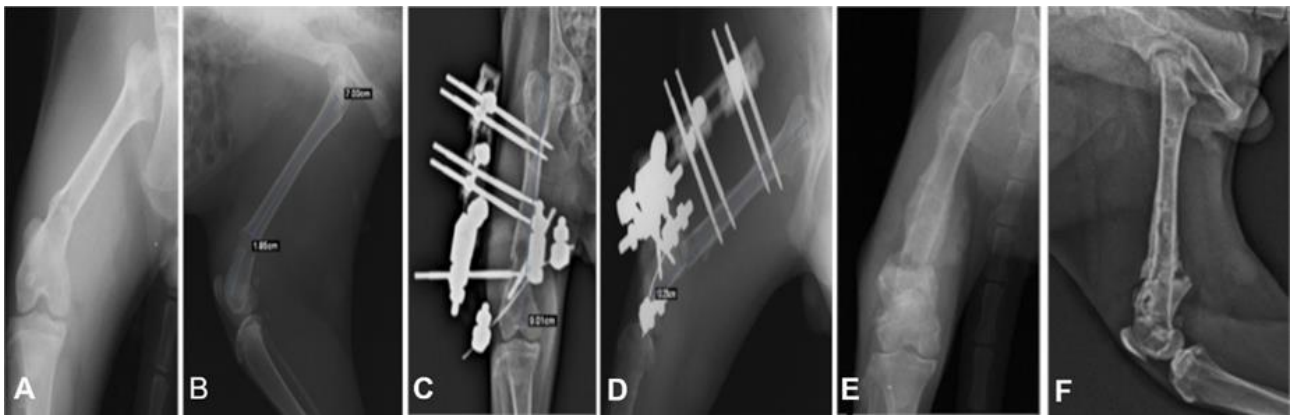

Figure 4. Case no. 8: X-ray images: (A) pre-operative A/P, (B) pre-operative M/L, (C) post-operative day 1 A/P, D) post-operative day 1 M/L (E) after the removal of fixator A/P, (F) after the removal of fixator M/L.

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Figure 5. Postoperative day 1, images of cats stepping on the ground, pertaining to (A) Case no. 1, (B) Case no. 2, (C) Case no. 5, (D) Case no.7.

Figure 6. Images for stepping on the ground after removing the fixator for (A) Case no. 1, (B) Case no. 2, (C) Case no. 5, (D) Case no.7.

Discussion and Conclusion

Classical cage resting (24), bandage, cerclage, screw, plate ve intramedullary pin (4, 23, 24) ve external fixation procedures (22, 23) are used for treatment of the fractures. It has been overemphasized that treatment method preferred in fractures should be minimally traumatic and easy-applicable as well as providing well-fixation (24). The treatment methods mentioned are routinely applied, but when intramedullary pin applications are evaluated, 6% more major complications are experienced compared to plate and external fixator applications (20). When plaque applications are considered, many major complications occur, especially in distal fractures (19). In addition, several factors such as open infecting wounds with regional material loss and formation of open infecting fractures due to perforation of skin caused by the fracture fragment preclude achievement of the desired stability and such circumstances direct the physicians to apply external fixator in the treatment of the fractures (11, 33).

When linear external fixators and circular external fixators are compared, both have advantages over each other in different subjects. Linear external fixators; While it can be applied in many fractures, provides simple assembly and disassembly, it has been determined that circular external fixators have superior biomechanical properties. However, application difficulties, requiring more intensive post-operative care and low tolerance for the patient are important disadvantages (17, 32). Hybrid external fixators are formed by connecting linear external fixators to circular external fixators. These fixators can be applied in deformity corrections, and they are versatile in fracture repair and can be applied in different fracture types with configurations (17, 37). Hybrid external fixators are applied more easily and in a short time compared to circular external fixators, are better tolerated by the patient and allow postoperative frame adjustments (28, 30). Hybrid external fixators have important advantages over linear external fixators in fracture repair because they have some positive features of circular external fixators. These advantages are; These are important criteria such as fixing the fragments or small bone fragments with stretched thin krishner wires, resisting bending forces, preventing torsional displacements that are negative for the bone, and accelerating bone healing by allowing the formation of axial micro-movement (17). In the present study, hybrid external fixator system was used in the treatment because of fracture line was localized at the distal femur in 10 cases constituting the study population and 4 cases had open fractures. Thereby, it was targeted to minimize complications as well as potential treatment-limiting factors in the cases. Additionally, advantages of the system such as early onset of joint motions, concurrent treatment of soft and bone tissue, allowance to perform closed reduction and achievement of biological biosynthesis were used (6). In the present study, 2 and 8 cases were operated using closed reduction and limited open reduction techniques, respectively. During the study it was monitored that the related extremities can be used in all cases after the postoperative 1^{st}-2^{nd} days. Daily wound care was carried out without complication in the cases with open wound. Thanks to these advantages, hybrid method was evaluated to be an applicable and useful technique in small pets.

The diameter of the ring used in the hybrid external fixators is one of the most essential criteria that determines the biomechanical compatibility of the fixator (9, 18). Increased ring diameter leads to increased length of the wire placed on the ring and decreased stability. It is recommended as a general rule that diameter of the ring should not exceed 1.5-2 fold of the extremity diameter (12). Accordingly, the present study has aimed to use the smallest ring as possible as and use of the rings with a diameter of 50-70 mm was found to be more considerable. On the other side, finger fixator that sends at least 4 Schanz pins and facilitates distraction and compression by allowing unilateral application of pins was used in the linear fixator part of the hybrid external fixator system.

One of the most important factors that affect the stability of the hybrid system is diameter of the wire. It has been essentially reported that increasing diameter of the wire increases the stability of the system (25). However, some authors have advocated that application of large-diameter wire may cause osteoporosis and reduced bone stability, therefore the diameter of the pin or wire should be meticulously selected. Nevertheless, it has been reported that diameter of the wire should not exceed 20% of the diameter of the bone that the system will be applied (2). Ferretti (8) reported that the use of wires with a diameter of 1.0-1.6 mm on cats and dogs in his study give positive outcomes. In the present study, these data has been taken into consideration and are used 1-1.5 mm Kirschner wire and 2.5 mm Schanz pin. No complication such as breaking of the wire or ruptur occured in the cases is not observed during the study. In addition, radiological examinations indicated no finding of complication in the bone tissue. It has been concluded that diameter of the wire used in the study is appropriate for bone tissue and patient weight.

In the present research, it has been determined that operation duration ranged between 65-150 min depending on the state of the fracture. The operations were performed using hybrid external fixation system and applying two different techniques as closed reduction external fixation and limited open reduction external fixation. It has been emphasized in the studies (5, 11). that experience is gained as the number of the practices increased and consequently

duration of the operation shortens. In this study, it has also been observed that the essential determinant factor for operation duration is the success of the intraoperative intervention. It has been monitored that repeats of the practice dramatically shortened the operation duration and this fact has been accepted as an important advantage of the technique.

It has been noted in a study on the treatment of humerus fractures in cats using hybrid external fixator that administration of ceftriaxone sodium (22 mg/kg) or the combination of amoxicillin clavulanic acid (20 mg/kg) eliminated the formation of infection in the postoperative period (38). It has been reported in another study that pin-base infection was monitored in some cases after twice daily administration of cefotaxime (10 mg/kg) along postoperative 7 days, however, this condition caused no complication in the cases (34). In the present study, leukocyte count was tested weekly during postoperative two weeks and broad spectrum antibiotics were administered alone or in combination according to the results. Beside to this, tolfenamic acid (0.4 mg/kg) was used for 5 days to relieve the pain and inflammation in the postoperative period. Mild pin-base infection was identified in 3 cases whereas no complication of infection was observed in the other cases.

In the external fixator applications, use of 10% povidone iodine, 2% hydrogen peroxide or 0.05% chlorhexidine is also recommended for postoperative pin-base care (10, 34). Differently, Singh et al. (39) have reported that 0.9% NaCl can be used combined with antibiotic and povidone iodine for the same procedure. Bilgili et al. (**7**) have reported that a rifamycin-nitrofurazone impregnated tamponade is placed to the pin-bases and additionally the whole system is protected from the external environment by bandaging with compression bandage completely. In the present study, pin-base cleaning was performed twice daily using 0.1% rivanol (rivanolum 1gr) antiseptic solution within the first postoperative 5 days. In the following days, pin-bases were cleansed using 10% povidone iodine (Povidone®, Kimpa, Istanbul, Türkiye) every day. The whole system was protected from the external environment by bandaging completely using compression bandage. All the cases were hospitalized in the clinic for postoperative care during fracture healing (formation of bone callus) and removal of the fixator.

External fixator applications is providing significant advantage by allowing concurrent treatment of the fracture and soft tissue (15, 26, 39). By the hybrid external fixation system applied in the present study, the cases with open fractures were treated with open wound care. For this purpose; initially antiseptic rivanol solution within the first 3 days and subsequently wound bandage containing the mixture of Centella asiatica (Madecassol®), nitrofurazone (Furacin®) and rifamycin sodium (Rif®) was applied. Consequently, improvement was achieved in open wounds of the cases within 13-21 days. External fixator applications allow mobility of the related extremity without loss of position in the fracture fragments and weight-bearing. Thereby, functional impairments in the joints, muscles and bones as well as muscular atrophies that occur due to application of other treatment methods can be minimized (15, 26, 39). In a study on the treatment of fractures using intramedullary pin, it has been reported that the time elapsed to bear weight on the related extremity may range between 1-2 weeks (26). Contrarily, Silva et al. (38) investigated the treatment of humerus fractures using hybrid external fixator in cats and reported that bearing weight on the related extremity occurs within postoperative 1-3 days. In a similar study carried out using circular external fixator, it has been stated that the related extremity can be used within postoperative 1-3 days (35).

It has been emphasized in another study which applied hybrid external fixator for femoral fractures in dogs that time elapsed to use the related extremity varied between 3-6 days (35). On the other hand, in a study (30) conducted on 49 dogs it has been stated that time elapsed to bear weight on the extremity varied between 1-38 days (averagely 8 days), while in another study (22) carried out on 30 dogs it has been reported that bearing weight started on the postoperative 1st, 7th- days in 8, 13 and 9 cases, respectively. In the present study, in all cases it could be beared weight on the related extremities within the postoperative 1-2 days. The findings of mild and moderate lameness were identified in 6 (Cases 1, 4, 5, 7, 8 and 10) and 4 (Cases 2, 3, 6 and 9) of the cases, respectively.

It has been reported that the decrease in the sharpness of the fracture edges, the disappearance of the fracture line and the callus structure are taken into account in the radiological evaluation of fracture healing (16, 36). Although, it is known that fracture edges usually become indistinct within the postoperative 5-7 days and bone callus formation become visible within 10-12 days, Piermattei et al. (27) have stated that fracture edges are remarkable in the first week whereas this markedness decreases in the 2nd week. Rao et al. (30) have noted in their study that consolidation starts by the 15th day and formation of bone callus becomes visible after 21th day. The researchers have detected that corticomedullary continuity returns in the postoperative 45-60 days in all the cases and reported that time elapsed to remove fixators averagely ranges between 30-60 days. Sailaja (34) has reported in his study conducted on 6 dogs that callus formation started on the 3rd week in all the cases and fixators were removed after completion of fracture healing on the postoperative 5th and 7th weeks in 3 and 3 cases, respectively. Sancak et al. (35) in their study in which treated tibial fractures in cats using circular external

fixator, reported that healing time and time elapsed for fixator removal were 35-55 days, respectively. In the present study, the time of onset of callus at the fracture line; It was determined as the post-operative 7th day in 9 of the cases and the 10th day in 1 case. Consolidation was completed in 4 weeks in 2 cases, in 5 weeks in 2 cases, and in 6 weeks in 6 cases. It was determined that secondary fracture healing occurred in all cases. Fixators were removed 1 week after the consolidation was completed. These results show that, as in similar studies, HEF provides a tight fixation and relatively reduced fracture healing times thanks to its biomechanical advantages in our cases. External fixators are associated with several complications such as wound formation in soft tissues, pin-base infection, pin loosening, pin inclination and pin fraction (11, 12). Rao et al. (30) have reported complications such as mild pin-base infection, loosening of K-wire, wound formation and mild radius/ulna deformity in their study. However, it has been emphasized that complications experienced in the research did not impair the stability of the fixator and that excellent improvement was achieved in all the fractures. Silva et al. (38) have noted in their study that it has been detected pin loosening as a complication in only 1 case on cats. Mutlu and Özsoy (22) have expressed in their study that it is encountered pin-base infection in 10 of 30 dogs and that this complication occurred due to the neglection of the pet owners. In the present study, all the cases were hospitalized in the clinic to perform their postoperative care, nevertheless, edema was monitored in 3 cases (Cases 1, 6 and 7) on the postoperative 1st day. However, edema that emerged in the extremities on the postoperative 2-3 days was found regressed by medical treatment. Pin-base infection and secondary soft tissue infection developed in totally 3 cases (Cases 2, 3 and 6). However, complication was eliminated by increasing the number of daily pin-base cleansing procedures. A mild inclination was detected in the Schanz pin applied to the distal fragment in 1 (Case 5) of the cases, but no intervention was performed since no impairment occurred in the reduction. The formation of a new fracture was discovered in Case 3 on the postoperative 4th day in the related extremity due to the excessive mobility, and the patient was re-operated and reduction was renewed. The complication was eliminated by adding 1 piece of Schanz pin to the ring applied on the distal fragment. Despite complications, healing time of the patients were found not to be affected negatively similarly with the other studies (22, 36).

In the present study, treatment of distal femoral fractures was achieved using hybrid external fixators in the cats with various breeds, age and sizes. The results revealed that application of hybrid external fixator system was well-tolerated by the cats, system allowed micromobility between the fracture fragments and consequently healing was achieved in a shorter time period. In addition, it was observed that postoperative care also contributed to the positive outcome of the treatment success and that healing time was similar with previous studies in the literature (36, 38). It has been monitored that this system provided many options to perform various interventions on the fragments including rotation in the postoperative period. Besides, it has been discovered that system allowed closed reduction and thereby decreased the infection risk significantly.

Considering the data obtained, it was predicted that hybrid external fixation system provides contribution to biological osteosynthesis within a shorter period compared with the other techniques. As a result, it has been concluded that carrying out comprehensive studies applying hybrid fixator system at the fractures in the appropriate sites would be beneficial in discovering ideal combinations of the system and expanding its application field by developing novel economic alternatives.

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Conflict of Interests

The authors declared that there is no conflict of interests.

Author Contributions

AG and İA designed the study. AG did the preoperative and post operative care of the patients AG applied the operation technique. İA evaluated the results. AG and İA wrote the manuscript. İA provided technical and supervisory support.

Data Availability Statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

Ethical Statement

This study was carried out after the animal experiment was approved by Siirt University Local Ethics Committee (Decision number: 2018/16).

Animal Welfare

The authors confirm that they have adhered to ARRIVE Guidelines to protect animals used for scientific purposes.

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