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Retrospective Evaluation of Challenging Delayed Union and Non-union Encountered in Dogs: 16 Cases (2012-2018)

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ABSTRACT: This case series aims to showcase some challenging delayed union and non-union cases, explain their possible causes and the treatment processes they underwent. Most non-union cases included in this study required at least two surgical interventions.The main reasons for the consecutive interventions were compromised vasculature of the soft tissues due to extreme trauma and infection. The final successful procedure for cases with excessive soft tissue trauma was external fixator application. Bone plates were more successful in cases where infection was the main cause of the non-union or in cases where poor owner compliance played a significant role. Minimally invasive external fixator application seems to be efficient in preserving the compromised vasculature of the bone while bone plates show better results in cases with localized infection.Using cerclage wires in non-union cases should be avoided because they hamper the periosteal blood supply. Harvesting bone grafts from the iliac crest was very practical, required little time and should be utilized in every possible non-union case.

Keywords: Bone healing; delayed union; dog; fracture;non-union.

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INTRODUCTION

Fractures require adequate stabilization and certain biological conditions to heal properly (Palmer *et al.*, 1992).Proper mechanical stabilization should be established by aligning fragments and reducing their movement while preserving the vascular supply of the bone (Nolte *et al.*, 2005).Failing to adhere to these principles result in delayed union or non-union (Karl and Benjamin, 2012).

Delayed union is the completion of the fracture healing in a longer time period than normal (Piermattei *et al.*, 2006). Despite taking longer, the fracture healing process is still maintained (DeAngelis, 1975). Non-union is characterized by the cessation of osteogenic activity on the fracture gap and requires surgical intervention. This might be viable or non-viable depending on the circulation present on the fracture site (DeAngelis, 1975; Piermattei *et al.*, 2006). Both complications have a similar aetiology and are multifactorial (Bartels, 1987). Mechanical causes include excessive fracture gap, insufficient stabilization, soft tissue interposition,motion at the fracture site and implant failure (Karl and Benjamin, 2012; Nolte *et al.*, 2005; Piermattei *et al.*, 2006). Damage to the periosteum, vascular supply or surrounding tissues, especially after high energy traumas or infections, are the main biological causes of delayed unions and non-unions (Karl and Benjamin, 2012; Piermattei *et al.*, 2006). In addition, patient-related factors such as age, metabolic disease, and high-dose corticosteroid usage have been reported to cause fracture healing complications (Bartels, 1987; Piermattei *et al.*, 2006).

Callus formation should be present at the fracture site in 7-12 weeks (Hohn and Rosen, 1984). If there is no osteogenic activity at the fracture site on a survey radiograph within that time frame, it is considered to be a non-union, if there is some osteogenic activity but no bony fusion, it is considered to be delayed union (Blaeser *et al.*, 2003).

The aim of this study is to evaluate non-union and delayed union cases encountered in our hospital in a 6-year period in an effort to isolate possible causes and evaluate successful treatment modalities.

MATERIALS AND METHODS

This study was approved by the Local Ethics Committee for Animal Experiments of Ondokuz Mayıs University (HADYEK Number: E-68489742-604.01.03-64040).

Dogs that were presented to animal Hospital of Ondokuz Mayıs University from 2012 to 2018 and diagnosed with delayed union or non-union were retrospectively evaluated. A total of 16 dogs (17 fractures) were included in this study; 12 dogs were managed in our hospital while 4 dogs (5 fractures) were initially managed in other private clinics. Earliest time of diagnosis follow up time, suspected aetiology, number of surgical procedures and stabilization techniques that were used were recorded.

Stabilization methods used were external coaptation, intramedullary pinning, external fixation (EF) (hybrid, tie-in, semi-circular external fixation [SESF],trans-articular external fixation [TESF]), plate and plate-rod combination. Autogenous cancellous bone grafts from the iliac crest were utilized in the revision surgeries of each non-union case, except for 13. The reason for not using grafts in that case was the presence of on-site infection which renders the graft non-viable (Gustilo and Anderson, 1976). The signalment, aetiology, fracture localization, fracture type, time after trauma to initial stabilization procedure and treatment modality were recorded (*Table 1*).

Clinical and radiological evaluations of each patient were done at their initial exam and 3 more times with two week intervals for a total of 4 clinical examinations through the duration of 6 weeks.If there were clinical signs such as instability at the fracture site, muscular atrophy, pain, lameness, and a non-established clinical union at the radiogram at the last check, the case was included in this study. Radiographic signs of a non-union fracture were closing of the medullary canal, presence of visible fracture gap, rounding of the fracture ends with bone resorption, and insufficient or excessive non-bridging callus formation. Non-union classification was performed according to Weber and Cech classification scheme (Weber and Cech, 1976).

The earliest instance of radiographic union was considered successful fusion and recorded as the recovery time.

RESULTS

The age of the dogs included in the study ranged from 12 months to 7 years (mean 3.46 years) and body weight ranged from 4 - 50kg (mean 28.1kg).The most common aetiology for the fractures was motor vehicle accidents (n=10), followed by gunshot injuries (n=5). Case history was unknown in one patient.

Table 1. Patient information and medical history

Case No	Signalment	Fractured Bone/Type/ Localization	History	Time After Trauma	Healing Complication	1stProcedure / Removal	2nd Procedure/ Removal	3rd Procedure/ Removal	Follow up Time	Radiographic Union Time	Cause
1	Kangal Shepherd, 5-y-old, M, 45 kg	R/U, Distal 1/3, Oblique, Closed	VT	3 days	Delayed Union	Hybrid ESF / 71 days	-	-	71 days	71 days	Infection
2	Golden Retriever, 3-y-old, M, 25 kg	Humerus, Distal 1/3, Comminuted, Closed	VT	10 days	Avascular Defect Nonunion	IM Pin+ Cerclage wire / 7 days	Tie-in ESF/ 85 days	Tie-in ESF / 151 days	344 days	243 days	Implant failure and infection
3	Rottweiler,1-y-old, F, 38 kg	Femur, Mid-shaft, Comminuted, Closed	VT	1 day	Vascular Hypertrophic Nonunion	DCP+IM Pin / 98 days	Tie-in ESF / 117 days	-	435 days	215 days	Cerclage wire
4	Mix breed, 2 y-old, F, 25 kg	Humerus, Distal 1/3, Oblique, Closed	VT	3 days	Vascular Hypertrophic Nonunion	Tie-in ESF+ Cerclage wire / 68 days	SESF / 99 days	-	167 days	167 days	Cerclage wire
5	Mix breed,3 y-old, m, 22 kg	R/U, Mid-shaft, Comminuted, Open Type I	GS	7 days	Avascular Necrotic Nonunion	Cast bandage / 40 days	DCP / 92 days	-	92 days	None	Infection
6	Mix breed,4 y-old, m, 18 kg	Humerus, Distal 1/3, Comminuted, Open Type I	GS	4 days	Delayed Union	Semi-circular ESF / 110 days	-	-	110 days	110 days	Infection
7	Golden Retriever, 1,5-y-old, M, 28 kg	Femur, Mid-shaft, Oblique, Closed	VT	1 day	Delayed Union	2xIM Pins+ Cerclage wires / 72 days	DCP / 240 days	-	312 days	312 days	Cerclage wire
8	Kangal Shepherd, 2-y-old, M, 30 kg	R/U, Proximal 1/3, Comminuted, Open Type I	GS	4 days	Avascular Necrotic Nonunion	TAESF / 78 days	Hybrid ESF / 72 days	-	150 days	None	Infection
9	Mix breed, 5 y-old, m, 15 kg	Tibia, Distal 1/3, Comminuted, Open Type I	VT	2 days	Avascular Defect Nonunion	IM pin/ 78 days	Semi-circular ESF / 120 days	DCP / 182 days	380 days	None	Infection
10	Mix breed, 4 y-old, m, 22 kg	R/U, Distal 1/3, Comminuted, Closed	Unknown	30 days	Vascular Oligotrophic Nonunion	IM pin (Radius) / 90 days	TAESF / 70 days	-	70	None	Insufficient Stabilization
11	Kangal Shepherd, 7-y-old, M, 45 kg	Tibia, Proximal 1/3, Comminuted, Open Type I	GS	4 days	Delayed Union	Hybrid ESF / 70 days	-	-	70	70 days	Infection
12	Mix breed, 1 y-old, f, 4 kg	Bilateral R/U, Distal 1/3, Transversal, Closed	VT	7 days	Vascular Hypertrophic Nonunion	Cast bandage / R and L 20 days	Hybrid ESF / R and L 120	Hybrid ESF / R and L 86	246 days	226 days	Insufficient Stabilization
13	Golden Retriever, 3-y-old, M, 32 kg	R/U, Mid-shaft, Comminuted, Open Type I	GS	0 day	Avascular Defect Nonunion	Hybrid ESF / 16 days	DCP / 138 days	-	179 days	154 days	Defect and infection
14	Golden Retriever, 3-y-old, M, 24 kg	Tibia, Mid-shaft, Comminuted, Open Type II	VT	20 days	Avascular Defect Nonunion	Tubuler Bone Plate+ Cerclage wire / 20 days	Semi-circular ESF / 130 days	DCP / 60 days	235 days	210 days	Infection and implant failure
15	Golden Retriever, 5-y-old, F, 28 kg	Tibia, Mid-shaft, Comminuted, Open Type I	VT	2 days	Avascular Defect Nonunion	DCP / 112 days	Semi-circular ESF / 90 days	-	267 days	202 days	Defect and infection
16	Mix breed, 4 y-old, f, 50 kg	Humerus, Mid-shaft, Comminuted, Closed	VT	1 day	Vascular Oligotrophic Nonunion	LCP / 10 days	Tie-in ESF / 120	Tie-in ESF / 153	317 days	283 days	Implant failure

VT: Vehicular trauma, GS: Gunshot trauma, R/U: Radius/Ulna, IM: Intramedullary Pin

Affected bones were radius/ulna (R/U) (n=7), tibia (n=4), humerus (n=4) and femur (n=2).Fracture localizations included proximal diaphyseal (n=2), mid diaphyseal (n=7) and distal diaphyseal (n=8). Fracture types were comminuted (n=12), oblique (n=3) and transverse (n=2).Eight fractures were open (type I: 7 and type II: 1).All open and comminuted fractures were non-unions except for cases 6 and 11.

Average time passed after trauma to initial stabilization was 7.25 (range: 0-30) days in non-unions and 3 (range: 1-4) days in delayed unions. Follow up time ranged from 70 to 435 days (mean 215.3 days). Detailed data concerning our cases are summarized in Table 1.

Initial stabilization methods used: bandage (n=3), intramedullary pin (n=4), ESF (n=6) [hybrid (n=3), Tie-in (n=1), SESF (n=1) and TESF (n=1)], plate (n=3) and plate-rod combination (n=1). The initial stabilization procedure of 4 cases were performed by veterinary clinics other than our hospital (cases 9, 10, 12 and 14). Four of 17 fractures were diagnosed as delayed union and 13 fractures as non-union (viable: 6, nonviable: 7) after stabilization.

The dog in case 13 suffered from a type I open comminuted fracture after being shot with a scattergun at close distance. The animal was presented immediately after the injury. A radiograph revealed a 43 mm bone defect in the left R/U combined with considerable soft tissue damage. The fracture was stabilized using a hybrid ESF after wound irrigation. Wound management was maintained after stabilization, but the frame had to be removed at the 16th day due to bone necrosis and infection. The bone was stabilized in a second surgical procedure with a DCP at the 41st day post trauma. The defect was filled with autologous cortico-cancellous bone graft. Follow up examinations of the dog were performed at regular intervals and fracture healing was complete at the 179th day after the initial trauma (Figure 1).

Implant failure occurred after initial stabilization in early postoperative period in three cases (case 2, 14 and 16). Case 2 had a humeral fracture that was stabilized using an intramedullary pin and a cerclage wire. Due to pin breakage at the 7th day, the bone was restabilized with a tie-in ESF, but there was anon-union at the 85th day due to failed maintenance and pin-site infection. The frame was removed and antibiotherapy was initiated and maintained for 3 weeks, until the infection has subsided. At the end of that time another tie-in ESF was put in place. Bone fusion was seen at the 151st day and the frame was removed but the patient was followed up for 3 more months.

Case 14 had an iatrogenic complication due to implant failure after a previous procedure with poor implant choice. The fracture was stabilized using a tubular neutralization plate that was too thin to bear weight. The plate was screwed in but also fixed in place using cerclage wires. The plate bent postoperatively and resulted in breakage of the suture line and exposure of the facture site. Despite this clinical out-

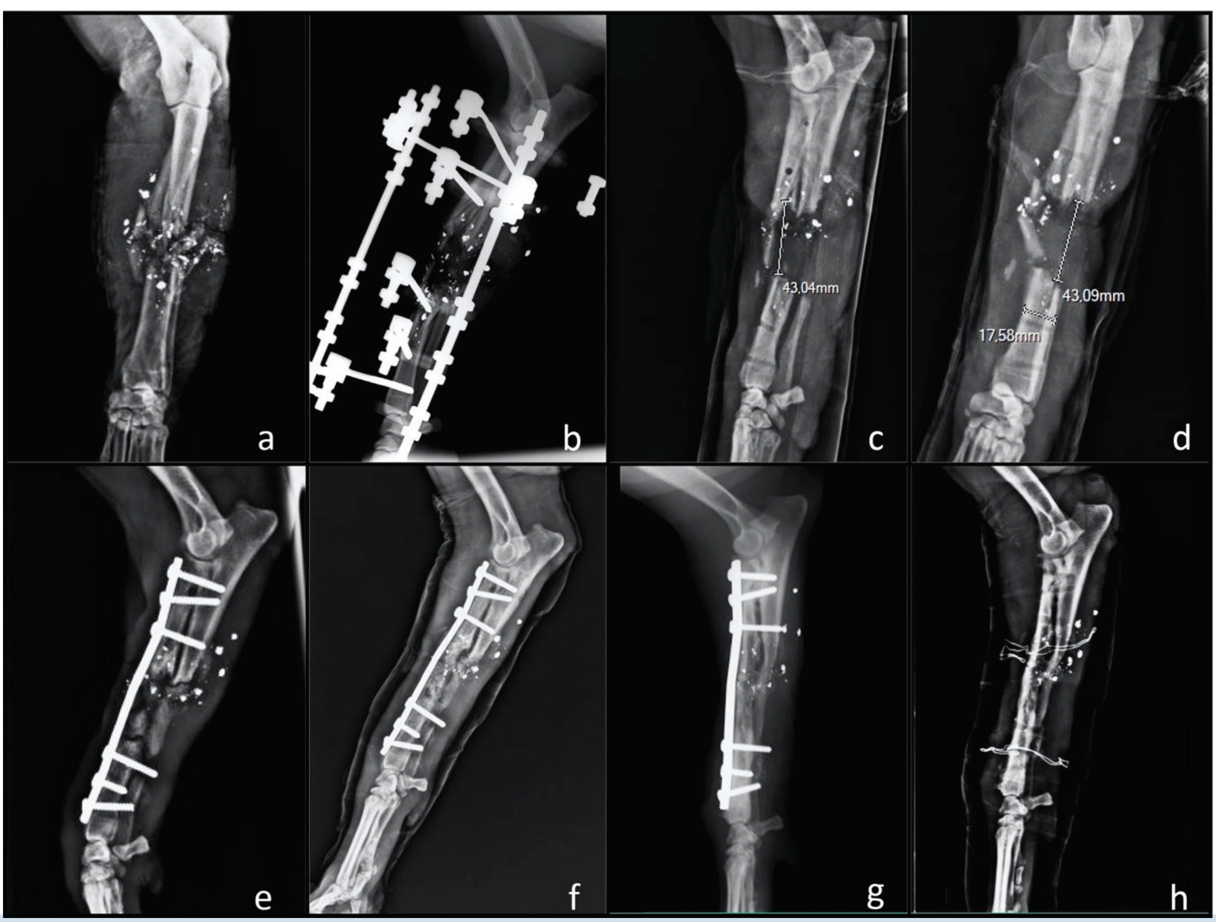

Figure 1. Lateral and craniocaudal radiographs of case 13. (a) Immediately after the trauma, (b) initial stabilization with SESF, (c) and (d) after removal ESF frame at 16. days, (e) second stabilizations with DCP and gap filled with bone graft, (f) bridging callus formation at 24 days after second surgical intervention, (g) and (h) healed bone at 179 days

come the veterinarian only managed the wound. At the time of presentation in our hospital (20 days after the initial trauma), a third of the plate and more than half of the tibial diaphysis were exposed. The plate and cerclage wires were removed and an SESF was applied. The SESF was kept in place for 130 days but the gap between the segments was still present. The frame was removed and a DCP was used to stabilize the non-union. The gap was bridged with callus at the 48th day after plate fixation. Sufficient fusion was achieved at the 60th day and at this point the plate was removed. The last follow up evaluation of the patient was performed 235 days after the initial trauma (Figure 2).

The comminuted humerus fracture of case 16 was first stabilized with a LCP but there was and implant failure and fragment stabilization was compromised at the first check in the 10th day. A tie-in ESF was applied in the same day. Despite callus was present and there was evidence of some osteogenic activity was extremely slow, so another surgery was scheduled, using the same stabilization technique and reapplying the graft. Adequate callus formation was seen on the radiography at the 153rd day and the frame was removed (Figure3).

Although stabilized using different techniques, case 3, 4 and 7 had cerclage wires to provide support of the stabilization. In those cases, osteogenic activity was absent only near the areas where the cerclage wires were placed (Figure4 and 5). In all these cases inappropriate cerclage wire use was noted. Case 3 and 7 regained their osteogenic activity once the cerclage

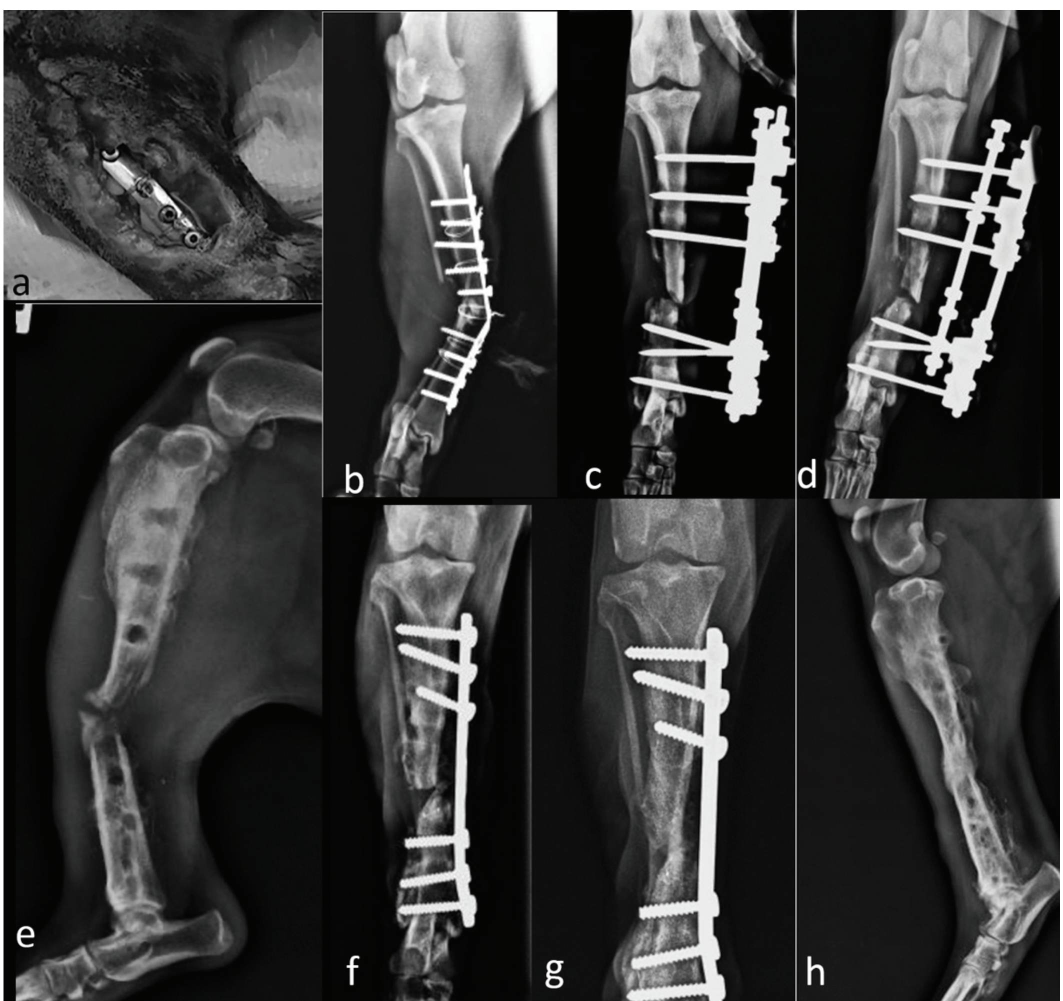

Figure 2. Clinical and radiographic views of case 14. (a) Clinical appearance of the exposed tibial mid shaft and (b) craniocaudal radiograph at the time of presentation, 20 days after surgery. (c) Craniocaudal radiograph after plate removal and SESF application, (d) on the 32th day and (e) on the 130th day,when the frame was removed. (f) Third surgical intervention DCP application, (g) bone was healed on the 60th day and (h) lateral radiographic view 255 days after trauma

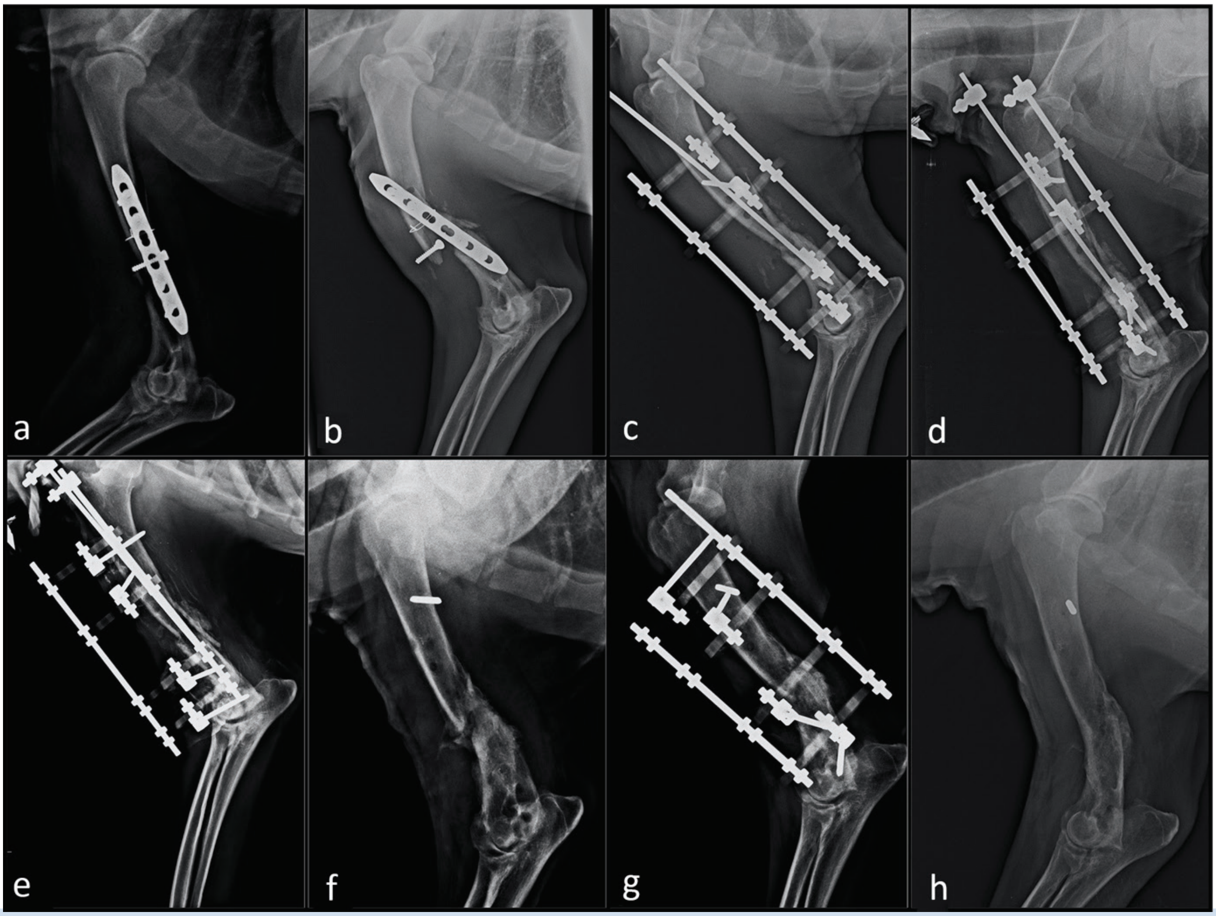

Figure 3. Lateral radiographic views of case 16. (a) Initial postoperative radiograph, (b) implant failure 10 days postoperatively. (c) Second surgical intervention with tie-in ESF configuration directly post-op, (d) on the 45th day and (e) after frame remove on the 120th day. (f) Third surgical intervention with tie-in ESF and (g) healed bone after 153 days

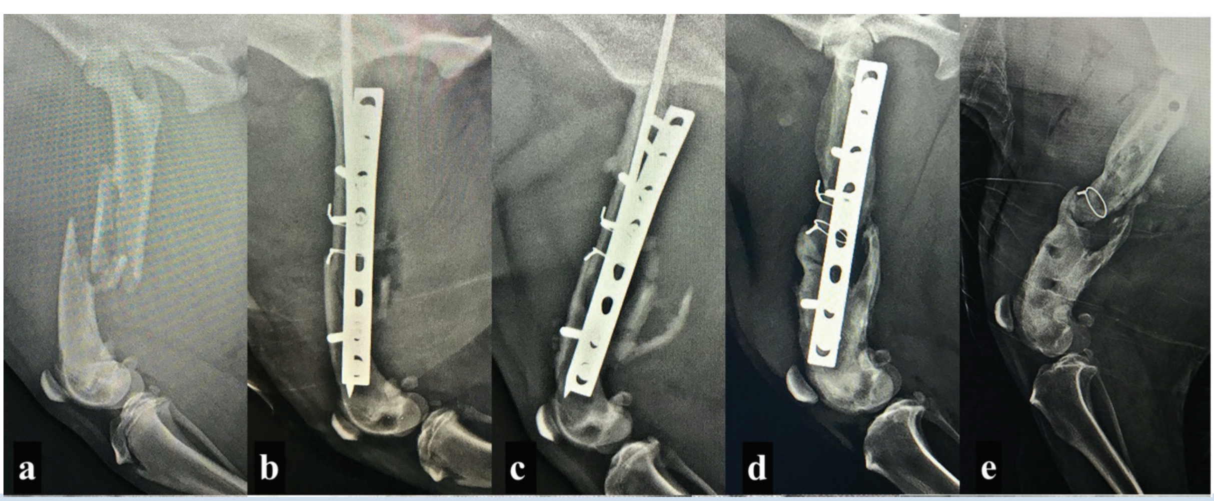

Figure 4. Postoperative survey radiographs of case 3. (a) pre op and (b) immediately post op, (c) on the 60th day, (d) on the 98th day before and (e) after plate removal

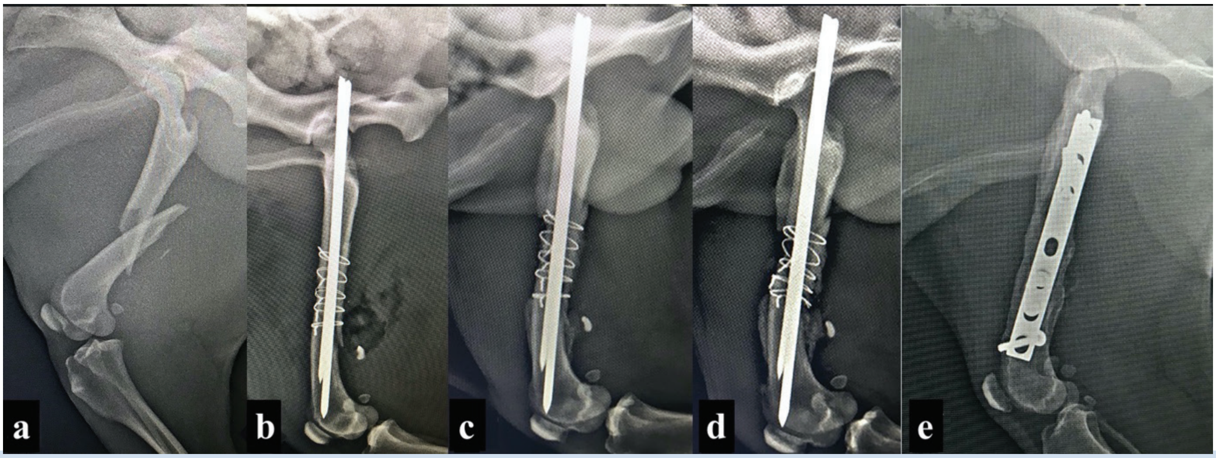

Figure 5. Postoperative survey radiographs in case 7. (a) pre op and (b) immediately post op, (c) at 34th day, (d) at 72th day before second surgical procedure and (e) at 240th day after second surgical intervention

wires were removed. The wire was imbedded inside the bone in case 4, which made it impossible to remove. This fracture healed with a bridging callus.

Case 1 and 11 were treated with hybrid ESFs and case 6 was managed with a SESF. These cases healed late and were classified as delayed unions. Case 6 developed a pin tract infection which was managed with antibiotic treatment.

Case 15 was first treated with a DCP but due to infection, the plate had to be removed at day 112 after surgery. SESF was applied and the antibiotic treatment was carried on for 14 days. There was adequate callus formation at the 90th day after the second procedure so the frame was removed.

Radiographic union was seen in 12 of 16 cases (All cases except 5, 8, 9 and 10). No further surgical intervention was attempted in these 4 cases due to owner's decision. Patient information, fracture types, surgical procedures and the timelines between procedures were given in table 1.

DISCUSSION

Radius/Ulna fractures in toy breeds are challenging; various different stabilization methods such as miniature circular external fixator, paraosseous clamp-cerclage, mini locking plate and free-form external fixators were reported for their management (Aikawa *et al.*, 2019; Bierens *et al.*, 2017; Kang *et al.*, 2016; Manchi *et al.*, 2017). Despite having a high incidence of complications for R/U fractures (Lappin *et al.*, 1983), external coaptation is the most widely available and cheapest option. Because of this it is often chosen due to financial considerations. Since using an external coaptation in a distal R/U or tibia fracture is more likely to result in a delayed union or non-union (Bartels, 1987; Piermattei *et al.*, 2006; Ramírez and Macías, 2016), we think the patient owner might actually end up paying more for consecutive surgeries.

In our study, the most often used and successful technique for treatment of non-unions and delayed unions was ESF application. Using an ESF is usually less invasive than other techniques and allows for some micro axial movement at the fracture site, which propagates circulation. The biggest drawback of using an ESF is probably its maintenance; the insertion sites must be kept clean, otherwise there is a risk of infection. This fact also makes the use of external fixators dependant on owner compliance. Bone plates were also successful, but their placement requires greater exposure and dissection. Despite posing greater risk for damaging the bone blood supply, the stabilization they provide is excellent and they require no maintenance. Barring complications, bone plates may be kept in place for extended periods of time, making them ideal for use in delayed unions. In our opinion, the technique selection for treatment of these cases should be determined by the following factors: Owner compliance, financial considerations, patient's demeanour, fracture type and reason for the non-union/delayed union (infection, necrosis etc.). Using an ESF with a neglectful owner could lead to complications, as seen in case 2. Despite that the fracture was operated twice using the exact same technique and surgeons, the second time led to success because the dog's handler was warned about the repercussions and maintained the ESF adequately.

In cases of severe trauma, vascularization to the tissues must be preserved, as they require constant blood supply to survive and heal (dos Santos *et al.*, 2016). External fixation is usually a good choice for this as some frames allow more options for pin insertion sites (Arnault *et al.*, 2011; Marcellin-Little, 2003; Yardimci *et al.*, 2018), the risk of meeting old pin/screw holes and creating iatrogenic fractures may be avoided.

Cerclage wires are commonly used for stabilization of long oblique fragments. A fracture is considered as a long fragment if it is 1.5-2 times the bone diameter (Schrader, 1991). In such fractures, the widely accepted method is to apply two cerclage wires on the long fragment as a single one is not enough for stabilization and proper application rarely leads to complications unless it becomes loose (Schrader, 1991). The blood supply provided by periosteal vessels are superior to medullary vessels, especially during early callus formation (Rhinelander, 1968), and according to some researchers, cerclage wires may impede the blood supply of the periosteum but not of the vessels traversing through the cortex or medullar canal (DeCamp *et al.*, 2016a; Rhinelander, 1968). The cerclage wire must be applied steadily, using just enough force to snugly hold the cortex and preserving the wire's integrity. Any soft tissue attachments to bone fragments or segments must be preserved to avoid sequestration (DeCamp *et al.*, 2016a). Disruption of the bone's blood supply with multiple cerclage wires could be a major cause of delayed union in this study. Lack of bridging callus in cases 4 and 7 may be attributed to interruption periosteal blood supplies by cerclage wires. The delayed unions in case 4 and 7 and non-union in case 3 may have occurred due to multiple cerclage wire application interfering with periosteal blood supply.

In case 4 and 7, thin cerclage wires were used folded upon themselves because we lacked wires of proper thickness. This may have impeded periostal vessels and caused delayed union; the radiographs confirmed lack of bridging callus only on the cerclage sites. The long oblique fracture of case 7 required a large number of wires (5) to be placed in order to counter the shearing force. In one case (number 3) with non-union, cerclage wires were properly placed but there was no evidence of vascularization around the wires at day 98. The avascular segment was seen again only around the cerclaged site. Each of these cases underwent revision surgery, utilizing bone grafts and removing the cerclage wires around the cortex except for case 4 in which the bony callus covering the wire made it impossible to remove.

Delayed unions and non-unions are caused by a host of reasons including, but not limited to, the presence of large defects, inadequate stabilization/excessive movement of the bone fragments, infection, damage to the vascular supply of the bone due to the trauma and poor implant placement. Localization of the fracture also plays a role, as the vascularization and structure of long bones vary. According to previous studies, non-unions are most frequently seen in radius/ulna, femur, humerus and tibia (Atilola, 1984; Bartels, 1987). In addition to this, comminuted fractures and large bone defects have a higher incidence of delayed union or non-union and these are more common in distal long bone fractures (i.e. radius/tibia) (Bartels, 1987; Piermattei *et al.*, 2006; Ramírez and Macías, 2016). Healing complications were mostly seen in R/U in this study (n=7) which is comparable with previous literature (Atilola, 1984; Bartels, 1987; Ramírez and Macías, 2016). Four of these fractures were located at the distal diaphyses, which is known to be least vascularized part of radius (Aikawa *et al.*, 2018; Bierens *et al.*, 2017; Gibert *et al.*, 2015; Ramírez and Macías, 2016).Since radius and ulna are the most "vulnerable" bones to delayed union and non-unions because their lack of rich blood supply, every effort must be made to preserve soft tissue intergrity in this area. For this reason the fracture must be stabilized using the least invasive method available.

Implant failures such as implant fatigue or implant loosening can occur due to various forces applied on it (DeCamp *et al.*, 2016b). The Schanz pin used in case 2 broke between its core and the start of its threads, which is its weakest point, and disrupted the fracture line's stability. Case 16 was initially fixed with a locking plate but the fracture line destabilized due to the short bridge plate.

Gunshot wounds are exceptionally high energy traumas and are especially dangerous because of their velocity and impact force. Additionally, as the projectile enters the tissue, changes in atmospheric pressure cause dirt and debris enter the freshly opened wound and contaminate the site, which has devastating consequences; the peripheral damage also disrupts the blood supply (Arnault *et al.*, 2011; Bebchuk and Harari, 1995; Pavletic and Trout, 2006). Shotguns fired at close range usually cause to more severe damage to soft tissue and bone than high velocity rifles (Frost and Grier, 1985). The high energy traumas in this study were comprised of 5 gunshot wounds. Two of these 5 cases were delayed unions as a result if infection. Even though antibiotic treatment was initiated immediately, the infection persisted in those cases long after surgery resulting in delayed union in case 6 and 11. These cases were managed by long term antibiotic treatment and daily wound irrigation without removing the SESF frame. When bony fusion was seen in follow-up radiographs, the ESFs were removed and the patients were discharged. Outcomes of these two cases suggest that ESF is helpful in persisting infections because it allows constantly irrigating and cleaning the infected site while providing stability to the fracture site. In our gunshot wound cases, infection, damaged vascular supply and necrotic bone fragments were primary reasons for delayed union and non-union.

According to previous studies, stabilization of fractures within 5 days after trauma will decrease incidence of non-union (Bartels, 1987; Wilber and Evans, 1978). Also fracture reduction becomes increasingly difficult with time passed due to displacement of bone fragments (Bartels, 1987). The delay between trauma and treatment in this study ranges from 1 to 4 days for delayed union cases and 0 to 30 days for non-union cases. The time between trauma and treatment is certainly an important factor for bone healing but there are several other variables such as infection, force of the impact or presence of infection so it is difficult to definitively assess in a study of this scope. The average time between trauma and surgery in this study was 7.25 days (between 0 and 30 for 12 cases) for non-union and 3 days (between 1-4 days for 4 cases) for delayed union.

While half of the non-union cases were more than 4 days old (6 out of 12) we believe compound fractures and infected open fractures have a high incidence even when treated immediately. Passage of time gradually increases the difficulty of surgery when stabilizing fractures. However in gunshot wounds it is advised to treat the infection for 24-72 hours before surgery (Bebchuk and Harari, 1995).In one of our cases (13), we decided to operate almost immediately in order to save time and preserve what's left of the tissue, which turned out to be a mistake (Bebchuk and Harari, 1995; Doherty and Smith, 1995; Piermattei *et al.*, 2006).A previous study suggested that cancellous bone grafts should be used between 10-14 days, where the vascular granulation bed could supply the graft (Bebchuk and Harari, 1995; Marcellin-Little, 2003). The use of any graft in sites with infection should be avoided (Bebchuk and Harari, 1995). The main problems with this case (case 13) were the large fracture gap and the lack of graft survival, probably due to infection. We believe it would have been more prudent to control the infection before attempting surgery. If the infection was controlled, the bone graft may have been viable in this case at the first operation.

CONCLUSION

Fracture type, presence of infection, owner's compliance and long-term maintenance considerations are factored in when choosing the operation technique. Every delayed union or non-union case is unique and has its own challenges during the healing period. The common challenge in these cases is trying to preserve the already compromised circulation while dissecting the fibrous tissue coverage over the fragments. If the blood supply is compromised due to soft tissue damage, bone growth is impaired. Some causes such as high impact trauma or gunshots might cause delayed or non- unions, as the damage is already done, but iatrogenic causes can and should be avoided. Early intervention and graft usage in combination with infection control are key to successful treatment. Taking a swab from the trauma site and choosing an effective antibiotic according to the antibiogram result is crucial in infection control. In cases where long term rigid stability was required, bone plates offered the best results, but in most contaminated wounds, ESF use allowed for constant management of the wound. We conclude that having flexibility in treatment modalities give the best results, as each stabilization method comes with a different set of pros and cons. However, techniques that can provide long term stability with the least amount of tissue disruption should be selected when managing fractures that have a higher risk of being a delayed or non-union.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

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