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LONG-TERM OUTCOME OF COMPLICATIONS ASSOCIATED WITH FEMUR FRACTURE REPAIRED BY PLATE-ROD CONSTRUCT USING LOCKING PLATES IN NINE DOGS

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ABSTRACT
A retrospective study was conducted in nine dogs presented with fracture complications following femur fracture repair by plate-rod technique using locking plates. The objective was to assess the type of complication, the possible etiology of failure, the grade of lameness and the functional, radiographic and long term outcome of complication. The major complications observed were screw breakage, severe fracture instability, sciatic injury due to migrated IMR, secondary longitudinal splintered fracture, severe mal-alignment and quadriceps contracture; and the minor complications were pin migration, seroma formation, mild plate instability, slight mal-alignment, 'windshield wiper effect', screw loosening, hypertrophic callus and delayed union. The complications were mainly associated with the displacement of intra-medullary rod (IMR) due to incorrect placement of IMR or failure of IMR to establish frictional interlock with endosteal bone. The inappropriate selection of PRC for fixation of complex distal diaphyseal fractures and the lack of owner compliance in movement restriction also contributed to complications. Despite these complications, locking plates maintained adequate stability across the fracture site and yielded 'excellent' and 'good' functional outcome in two and six dogs, respectively and eight among the nine dogs showed 'good' radiographic outcome.

KEYWORDS: Fracture complication, plate-rod construct, locking plates, femur.

INTRODUCTION

Plate-rod construct (PRC) has evolved as an effective technique for the biological osteosynthesis of diaphyseal femur fractures in dogs with a success rate ranging from 90 to 98% (Reems *et al.*, 2003; and Shiju *et al*., 2010). Conventional plates like dynamic compression plates (DCP) and limited contact dynamic compression plates (LC-DCP) have been widely used in PRCs. From a biological perspective, the use of conventional bone plates in osteosynthesis has several limitations as the stability of these plates rely mainly on compression between the plate and underlying bone generated by adequate screw fixation by bony purchase and anatomic contouring (Gautier and Sommer, 2003 and Miller and Goswami, 2007). Hence, the disruption of periosteal vascular supply is obvious and this may retard healing of underlying bone.

The locking compression plate (LCP), in contrast, has fixed angle locking screws that lock with the plate, precludes the need for compression and contouring, and hence maintain minimal plate-to-bone contact even with unicortical purchase. Limited plate-to-bone contact minimize disruption of periosteum and soft tissues, preserves the periosteal and extra osseous blood supply and reduce consequent osteoporosis underneath a plate (Gardner *et al*., 2005 and Koch, 2005). Unlike the conventional plate which converts an axial load to a shear stress, LCP convert an axial load to a compressive force and remain as an ideal internal fixator (Gautier and Sommer, 2003 and Miller and Goswami, 2007). Reports on failures and complications encountered with the use of conventional plates in PRCs are available (Reems *et al.*, 2003; and Shiju *et al*., 2010). However, the literatures on complications met with the use of locking plates in PRCs for fracture repair are scarce. Hence the study was undertaken to determine the various complications encountered with PRC using locking plates in canine femur fractures post-fixation and its possible etiology, to grade the different types of fracture complication and to assess the functional, radiographic and long term outcome of complication.

MATERIALS & METHODS

The study was conducted during August 2016 to July 2017 in dogs presented with fracture complications following treatment for femur fracture by PRC using locking plates (Nebula Surgical Private Limited, Gujarat, India) at the Outpatient unit of the Teaching Veterinary Clinical Complex cum Referral Veterinary Polyclinic, ICAR-Indian Veterinary Research Institute (ICAR-IVRI), Izzatnagar, Bareilly, U.P. The dogs were designated serially from DI to DIX. Clinical records of outpatient unit were utilized for collection of necessary data regarding age, breed, sex, general condition, etiology of fracture, time lapsed during presentation, prior treatment given and body weight of the dogs presented. The presence of associated and concurrent musculoskeletal injuries during initial presentation for fracture repair was also recorded. The femur fractures were classified according to the nature and severity of fracture, location and orientation of fracture line and complexity of fracture based on orthogonal radiographic views. The fractures were assigned an Unger's class using a system described by Unger *et al*. (1990). Operative records such as time of repair, duration of repair and damage on soft tissue structures were also noted. The postoperative orthogonal radiographic views were utilized to determine the configuration and dimension of implants used and to assess the status of fixation. For all the constructs, the percentage of space occupied by intra-medullary rod (IMR) in the medullary cavity at the narrowest point of the bone was measured in addition to the screw density kept for plates in each construct.

Intra-operatively, soft tissue damage was scored as 1: severe trauma/tear on surrounding soft tissues, 2: moderate trauma/tear on surrounding soft tissues, 3: mild trauma/tear on surrounding soft tissues and 4: soft tissues intact, no damage. The status and position of implants immediately after fracture repair was scored as 1: complete failure of implant, 2: implants in normal position with slight loss of bone alignment, partially loosened screws/wires and partially or completely misplaced IMR, 3: implants in normal position with bone in alignment; but slightly loosened screws/bolts/wires and 4: implants in normal position and bone in normal alignment.

A consistent numerical lameness scoring system was used for evaluation of the overall limb function of dogs during walk and trot on the day of presentation as suggested by Gordon-Evans *et al.* (2007) and was scored as 1: continuous non-weight bearing lameness, 2: intermittent non-weight bearing lameness, 3: severe weight bearing lameness, 4: obvious weight bearing lameness, and 5: walks/trots normally. The patients were critically evaluated for fracture complications either single or multiple. The fracture complications noticed were graded as major or minor depending upon the severity of the lesion, based on the criteria devised by Dvorak *et al*. (2000). The functional outcome of the repair was scored as P (poor): non-weight bearing lameness, F (fair): permanent weight bearing lameness, G (good): intermittent weight bearing lameness and E (excellent): no lameness based on grading system adopted from Guerin *et al*. (1998) and Stigen (1999). The radiographic outcome of the repair was scored as F (fair): radiographically detected complications in fracture healing and/or signs of arthrosis, G (good): radiographically apparent complications in fracture healing and/or signs of arthrosis and E (excellent): healed fracture radiographically in full alignment with the bone axis, no signs of arthrosis using a scoring system devised by Meyer-Lindenberg *et al*. (1991). The long term outcome of fracture complication was assessed using a scoring system devised by Dvorak *et al*. (2000), which is a modified evaluation of treatment results presented by Guerin *et al*. (1998), Stigen (1999) and Meyer-Lindenberg *et al.* (1991), based on functional outcome and radiographic evaluation. The long term outcome was scored as P (poor): non-weight bearing lameness; radiographically detected complications in fracture healing and/or signs of arthrosis, F (fair): permanent weight bearing lameness; radiographically detected complications in fracture healing and/or signs of arthrosis, G (good): temporary, intermittent weight bearing lameness; radiographically apparent complications in fracture healing and/or signs of arthrosis, EF (excellent functionally): no lameness, however, radiographically apparent complications in fracture healing and/or signs of arthrosis and EFR (excellent both functionally and radiographically): no lameness; healed fracture radiographically in full alignment with the bone axis; no signs of arthrosis. The functional, radiographic and long term outcome was graded and scored on the 90th postoperative day. The summary statistics of parametric and non-parametric variables were expressed as mean and standard error, and median and range, respectively.

RESULTS & DISCUSSION

The present retrospective study reported the postoperative complications associated with the application of PRCs in the repair of femur fractures when locking plates were used to bridge the defect. Locking plates were preferred over LC-LCP from a mechanical perspective for their ability to act as an internal fixator as they have fixed angle stable locking facility. Bridging an area of comminution with LC-DCP was unsatisfactory and inadequate as it underwent plastic deformation or breakage early in the postoperative period or fatigue failure over an extended time period depending on the healing potential of the patient (Johnson *et al.*, 1991 and Hulse *et al.*, 1997). In addition, a highly stiffness broad DCP may induce a "stress-protection" effect on the bone underneath the plate and affect its healing potential (Tonino *et al*., 1976 and Carter *et al*., 1981). The complications observed in the study were seroma formation, hypertrophic callus, screw loosening, proximal or distal IMR migration, slight mal-alignment of fractured fragment, plate instability, sciatic injury due to migrated IMR, secondary longitudinal splintered fracture along proximal fragment, delayed union, quadriceps contracture, screw breakage and implant failure. Despite the complications, the outcome was good to excellent, both functionally and radiographically, irrespective of the type of complication except in a dog where an implant failure was encountered.

Signalment and clinical observations

The mean age (Mean ±SE) of the dogs was 31.33 ±10.81 months (range from five to 96 months) and the mean body weight (Mean ±SE) was 23.67 ±3.50Kg (range from 15 to 43Kg). The breed of dogs were Non-descript (four), German shepherd (two), Dalmatian (one), Saint Bernard (one) and Rottweiler (one). Of the nine dogs selected for the study, five were males and four were females. None of the dogs in the study received any treatment prior to presentation. The aetiology of fracture was road traffic accident in five dogs and the remaining four dogs had the fracture following fall from a height. The mean time lapsed (Mean ± SE) during presentation of dogs was 2.11 ± 0.68 (range from zero to five days). All the dogs selected for the study scored good general body conditions. The right femur was fractured in five dogs and the left in four dogs. Fracture associated injuries and concurrent injuries were not observed in any of the dogs. A similar clinical representation of canine fracture patients was reported previously by Reems *et al.* (2003) and Shiju *et al*. (2010).

The fractures in all the dogs presented with post-fixation complications were closed in nature. The fracture involved the proximal diaphysis in four dogs, mid-diaphysis in three and the distal diaphysis in two. Among the nine dogs, three dogs had simple long oblique fractures, three had comminuted non reducible wedge fractures, two had complex fractures and one dog had segmental fracture. The mean numbers of fractured fragments (Mean ±SE) including the main proximal and distal fragments were 5.89 ±1.62 (range from two to 17). Interestingly, Reems *et al.* (2003) has observed a reduction in healing time when fracture fragments were ≥5. The clinical outcome of fracture fixation is characterized by the weight bearing on the operated limb and the presence of pain during palpation of the fracture site (Bhandari *et al.*, 2002 and Starr, 2008). Of the nine cases presented, severe weight bearing lameness was observed in 5 dogs, intermittent non-weight bearing lameness was observed in 3 dogs and continuous non-weight bearing lameness was observed in one dog on the day of presentation with complication. Although lameness does not directly evaluate pain, it may be used as an indicator of pain (Hudson *et al.*, 2004). In the present study, animals showed varying degree of lameness and none of the animal showed normal gait in walk and trot. The lameness was obviously related to the loss of fracture reduction and alignment subsequent to migrated IMR and its interference with normal healing process. The median lameness score during walk and trot was 2 (1-3). The data on signalment and preoperative observations of each dog have been shown in table 1**.**

TABLE 1. Clinical record of dogs presented with complications

Dog No.	Age (months)	Breed	Sex (M/F)	Body weight (Kg)	Time lapse (days)	Aetiology	Side affected (R/L)	Prior treatment	Concurrent injuries	Unger class	No. of fracture fragments	Grade of lameness	
												Walk	Trot
DI	6	Dalmatian	M	16	1	FFH	R	Nil	Nil	32B3	5	3	3
DII	6	Rottweiler	F	23	1	FFH	L	Nil	Nil	32C3	9	2	2
DIII	66	Non-descript	M	22	4	RTA	L	Nil	Nil	32B3	7	2	2
DIV	48	German shepherd	M	36	5	RTA	L	Nil	Nil	32A2	2	2	2
DV	96	German shepherd	F	26	1	FFH	R	Nil	Nil	32C3	17	3	3
DVI	5	Non-descript	M	9	0	RTA	R	Nil	Nil	32A2	2	3	3
DVII	18	Saint Bernard	F	43	2	RTA	R	Nil	Nil	32C2	3	2	2
DVIII	30	Non-descript	M	23	5	RTA	R	Nil	Nil	32B3	6	1	1
DIX	7	Non-descript	F	15	0	FFH	L	Nil	Nil	32A2	2	2	2
Mean ± SE / Media	31.33± 10.8	-	-	23.67 ± 3.50	2.11 ± 0.6	-	-	-	-	-	5.89 ± 1.62	2 (1-3)	2 (1-3)

M: Male, F: Female, FFH: Fall from height, RTA: Road traffic accident, R: Right and L: Left

Intra-operative observation

The mean time of repair (Mean ±SE) after the fracture incident was 3.67 ±2.29 days (range from zero to three days). Intra-operative data revealed median soft tissue injury score of 2 (1-3) and required mean duration (Mean ±SE) of 58.33 ±2.35 minutes (range from 48 to 68 minutes) for completion of operative procedures. The time to repair and duration of surgery was highest in dog DVIII which was presented with major fracture complication. The prolonged duration observed in this dog if inferred as a cause of major complication, may remain due overstated; however, significant association among these variables have been reported by Reems *et al.* (2003). Open reduction and stabilization of fracture through an Open but Do Not Touch (OBDNT) approach was adopted in all cases. The IMR occupied 35% to 41% of the medullary cavity at its narrowest point in all the dogs. Hulse *et al.* (2000) and Pearson *et al.* (2015) suggested using an IMR occupying 35-40% of the diameter of the marrow cavity in clinical practice for physiological load sharing as it increased the bending stiffness and simultaneously decreased the plate strain. According to Reems *et al*. (2003), a larger diameter IMR engaging up to 50% of medullary cavity may be used in dogs that have lower healing potential in order to reduce the chances of plate failure. However, an IMR of at least 30% intramedullary diameter was required to increase the bending stiffness of PRC (Pearson *et al*., 2015). The minimum number of screws required for application of PRC has not been established. In the present study, plate fixation was achieved with either all bicortical screws or with mixed configuration of unicortical and bicortical screws and maintained a screw density of 0.62 ±0.03 (range from 0.5 to 0.77). Hulse *et al*. (2000) and Reems *et al.* (2003) suggested application of at least the distal screws bicortically and the remaining screws unicortically in a PRC. Although Reems *et al.* (2003) observed considerable stability without failure in all screw configurations, screw density >0.5 was maintained throughout. But, screw densities <0.5 or 0.4 have been suggested by Gautier and Sommer (2003) and Niederhauser *et al*. (2015) while bridging a comminuted fracture. In fact, the incorporation of an IMR which share the load on the plate precludes the need for meticulous considerations regarding the number of screws or the configuration of screws to be used.

In dog DIV with osteoporosis, the bone cortex was thin. In order to avoid the catastrophic failure of plate especially during torsional loading due to reduced working length of monocortical screws, bicortical screws were applied. The angle stable lock in a locking plate restricts the freedom to angle the screws in order to bypass an IMR necessitating unicortical application of screws. But the flared distal diaphysis and metaphysis provided sufficient room for bicortical placement of locking screw. Among nine cases, 3.5mm ×11mm (width) plates were applied in seven cases, 4.5mm ×14mm (width) and 2.7mm ×8mm (width) plate was applied in one case each. Cerclage wire was used in stabilization of long oblique, segmental, non-reducible wedge fractures to reconstruct the bony column. The intra-operative stability and alignment of bone in postoperative radiographs were excellent in 6 dogs with a median score of 4 (2-4). In dog II with distal diaphyseal fracture, the IMR failed to engage the distal condyle properly and in dog VI with proximal diaphyseal fracture, the IMR penetrated the opposite cortex at the level of distal diaphysis due to the excess curvature of bone. Accurate positioning and placement of IMR into the distal condyle of femur was mandatory to achieve stable fixation and hence effective PRC. Slight mal-alignment of distal fragment with the longitudinal axis of the proximal bone fragment was observed in dog V with distal diaphyseal fracture. The selection of PRC for fixation of complex distal diaphyseal fractures was found to be inappropriate. The intra-operative observations of each dog have been shown in table 2.

TABLE 2. Clinical record on intra-operative data of dogs presented with complications

Dog No.	Unger class	Time of repair (days)	Duration of surgery (min.)	Soft tissue damage	Screw density	IMR (%)	Status of fixation
DI	32B3	1	60	2	0.71	35	4
DII	32C3	4	65	1	0.62	38	3
DIII	32B3	6	53	2	0.5	36	4
DIV	32A2	5	60	2	0.77	40	4
DV	32C3	3	65	1	0.55	41	2
DVI	32A2	2	48	3	0.62	37	2
DVII	32C2	2	50	2	0.5	35	4
DVIII	32B3	8	68	2	0.66	38	4
DIX	32A2	2	56	3	0.62	40	4
Mean ± SE/ Median	-	3.67 ± 2.29	58.33 ± 2.35	2 (1-3)	0.62 ± 0.03	-	4 (2-4)

Type and grade of fracture complication

The complications observed in the present study have been shown in table 3. The complications were observed mostly in combination and were inter-related to each other. The major and minor fracture complications were observed in two and seven dogs, respectively. Similar group of complications were also observed by Reems *et al*. (2003) and Shiju *et al*. (2010) with PRCs using LC-DCPs. The IMR migration was the most common complication encountered in the early fracture healing phase. In a PRC, the bone-PRC stiffness probably lies in the relative motion between the bone plate and IMR during loading. Since the IMR and plate were not interlocked, the frictional interlock between the IMR and the cancellous bone was the primary factor holding the pin in position against loading forces. The complications observed were mainly associated with the displacement of IMR due to incorrect placement of IMR or failure of IMR to establish frictional interlock with endosteal bone (Hulse *et al.*, 1997 and Urbanova *et al*., 2010). It is also assumed that the stability of the IMR in a PRC could change over time because of micromotion at the IMR-cancellous bone endosteal interface. The interface being small, micromotion might generate high strain levels which can provoke bone resorption. The subsequent resorption may relieve the interface strain but creates a bigger cavity that would lower the tightness of pin fit ensuing IMR migration (Hulse *et al.*, 1997). Experimental monitoring of pin migration by Urbanova *et al.* (2010) led to the conclusion that the loading forces triggered displacement of the pin within the medullar cavity up to the stage at its compact fixture with the bone.

The IMR migration was observed in seven dogs which subsequently led to the development of associated complications. The IMR, migrated usually at 6th postoperative week, which was removed on the day of presentation, resulted in plate instability and slight mal-alignment of fracture fragments.

TABLE 3. The functional, radiographic and long term outcome of dogs presented with complications

Dog No.	Unger's class	Type of complication	Grade of complication, Dvorak *et al.* (2000		Functional outcome, Guerin *et al.* (1998) and Stigen (1999)	Radiographic outcome, Meyer-Lindenberg *et al.* (1991)	Long term outcome, Dvorak *et. al.* (2000)
			Major	Minor			
DI	32B3	Proximal IMR migration (6th week), mild plate instability (8th week) and hypertrophic callus (14th week)	-	+	E	G	EF
DII	32C3	Proximal IMR migration and distal end screw loosening (6th week), mild plate instability and loss of alignment of fragments (8th week)	-	+	E	G	EF
DIII	32B3	Proximal IMR migration (6th week), mild plate instability, loss of alignment of fragments (8th week) and delayed union (14th week)	-	+	G	G	G
DIV	32A2	Seroma formation (2nd week), longitudinal fracture of proximal fragment, proximal IMR migration and sciatic injury (6th week) and hypertrophic callus (14th week)	-	+	G	G	G
DV	32C3	Proximal IMR migration and distal end screw loosening (6th week), mild plate instability and loss of alignment of fragments (8th week)	-	+	G	G	G
DVI	32A2	Distal IMR migration (6th week) and hypertrophic callus (10th week)	-	+	G	G	G
DVII	32C2	Distal end screw loosening and slight mal-alignment of fragments (6th week) and delayed union (14th week)	-	+	G	G	G
DVIII	32B3	Proximal migration of IMR (6th week), screw head breakage, implant failure and severe mal-alignment of fragments (10th week) and quadriceps contracture with hypertrophic callus (14th week)	+	-	F	F	F
DIX	32A2	Proximal IMR migration (6week), distal end screw loosening (windshield wiper effect) and mild plate instability (10th week) and hypertrophic callus and delayed union (14th week)	-	-	G	G	G

E: Excellent, G: Good, EF: Excellent functionally and F: Fair

The IMR migration observed in dog DIV during the 6th postoperative week occurred subsequent to a longitudinal fracture on the proximal fragment of the osteoporotic bone which led to slight collapse of fracture site. Intermittent knuckling was also observed which may be a sign of concurrent sciatic nerve injury. The migrated IMR was re-inserted in dog IX, but recurrence was observed after 3 days and hence was removed. The radiolucent areas around the distal screws due to consistent instability gave a characteristic 'windshield wiper effect' appearance in the radiographs during the 10th postoperative week. The dog VIII developed major complication after fracture fixation by PRC using locking plate. Screw head breakage, implant failure and severe malaligment of fracture fragments occurred on the 10th postoperative week following removal of migrated IMR during the 6th postoperative week. This may be due to large unhealed defect persisted without load sharing between bone and plate. Screw breakage occurred directly under the screw head, near the screw-plate interface as reported previously by Boudrieau (2016). Sirin *et al.* (2013) reported a broken locking screw-head and attributed it to a defective screw. Locking screw heads are less likely to break since the difference between the core diameters of the screw shaft and head is much smaller than it is with conventional screws. Nevertheless, locking screws can break in case of chronic instability or increased strain as a result of rotational forces (Smith *et al.*, 2007). The same dog later developed quadriceps contracture during the 14th postoperative week. Complete transverse overriding re-fracture with broken plate and screws following IMR removal as reported by Shiju *et al*. (2010) were not encountered in our study. In dogs DII and DV with complex distal diaphyseal fractures, loosening of distal plate screws were observed. Radiographically hypertrophic callus was observed in dogs DI, DIV, DVI, DVIII and DIX and delayed union was observed in dogs DIII, DVII and DIX, on the orthogonal views during the 14th postoperative week.

Outcome of fracture complication

Gradual improvement in overall usage of operated limb was observed in all the seven dogs presented with minor complication and one dog with major complication. Cage rest and restricted movement were advised when these dogs were initially presented with complications. After an initial phase of mild instability due to an excess strain on the plate subsequent to migration of IMR and its removal, the locking plates achieved terminal compliance (von Pfeil *et al*., 2005). This allowed satisfactory stability and implant loading. Once the fracture healing progressed, the weight bearing was improved and hence also the functional outcome (Perren, 2002). The radiographically detected hypertrophic callus may be a sign of fracture instability due to implant micromotion which usually incites healing stress at the fracture site. Although collapse at the fracture site due to longitudinal splinter along the proximal fragment was observed in dog DIV, the bicortical screws sustained the fracture site instability. Knuckling also remised completely in this dog by 14th postoperative week. A revision surgery using ILN was attempted in dog VIII which developed major complication. During the 14th postoperative week, dogs DI and DII showed excellent functional outcome and all the remaining dogs except dog DVIII showed good functional outcome. All the dogs showed good radiographic outcome with apparent complications during the 14th postoperative week except dog DVIII. The long term outcome which is a combination of functional and radiographic outcome was excellent in two dogs, good in six dogs and fair in one dog. The different types of complications observed in each dogs and the outcome of complications have been shown in table 3.

Early postoperative loading led to migration of IMR and the removal of migrated IMR before adequate bone healing led to secondary loss of reduction and alignment, plate instability, screw loosening and implant failure, which ultimately resulted in delayed healing and/or development of hypertrophic callus. Despite the failures observed in the early postoperative period, functional outcome of operated limb was graded good to excellent in all the cases except in one dog presented with implant failure.

Although several physiological, pathological and conformational parameters in addition to type of fracture and technique of repair has been suggested to play an important role in fracture healing, the obligatory postoperative cage rest and movement restriction is imperative following fracture fixation by PRC especially when it is applied as load bearing implant (Jackson and Pacchiana, 2004). The postoperative care played the predominant role in the outcome of repair. The selection of appropriate technique, the expertise of the surgeon with the technique and the ability to overview anticipated complication during fracture repair remains as the last but not the least factor which determine the outcome of repair.

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