The Journal of Animal & Plant Sciences, 29(2): 2019, Page: 437-447
ISSN: 1018-7081

A PRELIMINARY INVESTIGATION ON EFFECTS OF TWO DIFFERENT CORTICAL-SCREW CONFIGURATIONS ON LOCKING PLATES FOR THE REPAIR OF SIMPLE DIAPHYSEAL LONG BONE FRACTURES IN DOGS

N. Kallianpur, K. Singh*, A. Gopinathan, S. B. Sarangom, P. Sharma, C. Sowbharenya and C. John

Division of Surgery, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India – 243 122
*Corresponding Author's Email: ksuppli@yahoo.co.in

ABSTRACT

The study was conducted on 12 client-owned dogs to evaluate the effects of two different cortical-screw configurations on locking plate fixation in simple transverse diaphyseal long bone fractures. Dogs were randomly divided into 2 groups (n = 6). In group A, locking screws were placed in bicortical configuration and in Group B, bicortical screws were replaced by unicortical screws except at the distal most holes. There was no significant difference (P>0.05) between groups with respect to age; body weight; time lapse; preoperative soft tissue status; early postoperative weight bearing; and postoperative limb function, stance and gait scores during progression, pain on palpation and manipulation, lameness scores and fracture angulations at different intervals. The surgical procedures were successful in all dogs. The duration of surgery was significantly short (P≤0.05) in group B. Fractures in both groups healed by primary gap healing with minimum callus formation and the radiographic healing time in group A was non-significantly less (P>0.05). Major postoperative complications were plate breakage, dislodgement of plate with far bicortical screw head breakage, pull-out of adjacent unicortical screw, and *enbloc* screw pull-out. Retrospective evaluation of the failures ruled out the possible involvement of cortical-screw configuration. An overall functional recovery was excellent in both the groups. In terms of screw-related complications, the bicortical screw configuration was superior to the mixed screw-cortex configuration despite the fact that the failures were not associated with screw-cortex configuration. The discernible advantages of mixed screw-cortex configuration were the ease of application and short duration of surgery. The findings substantiate that fixation of locking plates using unicortical-bicortical screw configuration provide adequate stability and enable fracture healing similar to bicortical screw configuration in simple diaphyseal long bone fractures in dogs. Further studies are necessary prior to regularization of mixed screw-cortex configurations in clinical practice.

Key words: Locking plate, long bone, bicortical screw, unicortical, locking screw, dog.

INTRODUCTION

Fracture fixation using Locking Compression Plate (LCP) is a relatively recent technique in veterinary practice with limited time-honoured guidelines for their use, primarily extrapolated from human literatures. The threaded heads of the locking head screws (LHS) lock firmly into the reciprocal threaded hole of the plate, providing angular and axial stability to the LHS relative to the LCP (Wagner, 2006 and Sommer *et al.,* 2007). In a locking plate, LHS can be placed either as unicortical by inserting along a single cortex or as bicortical, incorporating both the cortices (Johnson, 2013). The unique advantages of unicortical LHS, which have been proven beneficial, include preservation of endosteal blood supply (Goh *et al*., 2009), simplification of the plating surgery, avoiding potential over drilling or oversized screws (Dona *et al*., 2004) and reducing the risk of refracture after removal (Overturf *et al*., 2014 and Pater *et al*., 2014). The LHS in a locking plate bone construct doesn't solely rely on the pullout strength of a single screw or on maintaining friction between plate and bone and therefore, unicortical screw placement is thought to be sufficient (Thakur, 2007). On the other hand, the added pullout strength and torsional stability lent by bicortical screws are also imperative (Goh *et al.*, 2009). For added benefits of both these configurations, various combinations of unicortical and bicortical screw configurations in various positions have been tested biomechanically in cadavers (Niederhauser *et al*., 2015 and Nourisa *et al*., 2015). The previously assumed superiority of bicortical fixation over unicortical fixation or their combinations remains a subject of debate (Dona *et al*., 2004 and Roberts *et al*., 2007). Unicortical LHS are used clinically; however, the precise indications for their use are unclear (Dunlap *et al*., 2011 and Ramesh *et al*., 2015) and clinical comparative studies in dogs are lacking.

The objective of the study was to evaluate clinically the effects of two different cortical-screw configurations (bicortical v/s unicortical-bicortical) on locking plate fixation in simple diaphyseal long bone fractures in dogs. We hypothesized that fixation of locking plates using unicortical-bicortical screw configuration provides adequate stability and enable fracture healing similar to bicortical screw configuration for simple diaphyseal long bone fractures in dogs.

MATERIALS AND METHODS

The study was approved by the Institutional Ethics Committee, ICAR-IVRI, Izzatnagar, Bareilly, U.P. and an informed consent was obtained from the owner of each dog before any surgical procedures was performed.

Selection and grouping of cases: Twelve client-owned, active intact dogs referred for simple transverse diaphyseal fractures of long bones, deemed appropriate by the clinician for locking plate fixation, were selected for the study. The patients were randomly divided into two groups, A and B, having 6 animals each. In group A, all locking screws were placed in bicortical configuration to fix the plate, while in Group B; bicortical screws were replaced by unicortical screws except the distal most screws (end screws) to form a unicortical-bicortical configuration [Fig. 1]. In both groups, the dogs were numbered serially from A1-6 and B1-6, respectively. Dogs with concurrent injuries, nutritional and metabolic disorders of bone and simultaneous infectious and non-infectious diseases were excluded from the study.

Anaesthesia: All the dogs were premedicated with atropine sulphate (Atropine sulphate, Hindustan Pharmaceuticals, Barauni, India) at the rate of 0.04 mg/kg body weight (bwt) as intramuscular injection. After 15 minutes, dexmedetomidine (Dextomid, Neon laboratories limited, Mumbai, India) at the rate of 15 µg/kg bwt intravenously (i.v.) followed by butorophanol (Butrum-1, Aristo Pharmaceuticals Pvt. Ltd., Raisen, India) at the rate of 0.05 mg/kg bwt i.v. were given through an intravenous catheter inserted in the cephalic vein. Anaesthesia was induced using propofol (Neorof, Neon laboratories limited, Mumbai, India) at the rate of 4.4 mg/kg bwt i.v. and maintained with 2% isoflurane in oxygen. Preoperatively, cefazolin (Reflin, Ranbaxy Laboratories Limited, Mumbai, India) at the rate of 22 mg/kg bwt i.v. was given half an hour before premedication.

Surgical procedure: The surgical site was aseptically prepared and the fractured bone fragments were approached *via* standard surgical procedures for each bone for open reduction and placement of bone plates. Efforts were made to preserve soft tissue attachments to enable vasculature enhanced healing. After adequate fracture reduction, the plates were placed and locking screws were applied under manual compression. The size of the bone plates used in each patient was determined on the basis of body weight, bone size and the length of fracture, adopted from guidelines used for conventional plating (Koch, 2005). Accordingly, appropriate locking plates (Nebula Surgical Private Limited, Gujarat, India) made from medical grade 316L stainless steel metal alloy of size 2.7 and/or 3.5mm, as applicable for each patient were selected. Prior to placement, the plates were contoured according to the bone curvature, as needed; then afterwards, all screws were inserted in neutral locking position, either in bicortical or unicortical-bicortical configuration, based on the pattern the patient was assigned randomly. The appropriate screw length was determined using a depth gauge after drilling the screw holes, i.e. either including *cis* cortex alone or both the *cis* and *trans* cortices, under the guidance of a universal locking drill guide. Self-tapping screws were placed using appropriate hexagonal screw driver until the screw head threads got completely locked on to the plate threads. The screw holes adjacent to the fracture line were applied first, while those distal to the fracture site were applied last. Lavage of operative site was done with sterile normal saline solution (0.9%) to clear debris, if any. The soft tissues were apposed over the fracture site and the skin incision was closed routinely. All the procedures were performed by the same surgeon who assessed the intra-operative observations and the preoperative soft tissue inflammation. Cranio-caudal and medio-lateral projections of the fracture site were obtained immediately after the surgeries and were examined for implant positioning and alignment, and adequate fracture reduction. Postoperative antibiotics were prescribed in those cases where a perioperative break in asepsis was suspected, and postoperative analgesics were administered, as deemed appropriate by the surgeon. Antiseptic dressings were done regularly until the skin sutures were removed. As additional precautions, restricted movements were advised for 4 to 6 weeks after the surgery.

Data collection: All the necessary information regarding age, body weight, sex, breed, etiology, time elapsed (duration of occurrence of fracture till clinical presentation), bone involved, concurrent injuries and general condition of animals were recorded. The condition of soft tissue of the affected region on the day of presentation was scored as 1 (no inflammation, pain, oedema), 2 (mild inflammation, pain, oedema), 3 (moderate inflammation, pain, oedema) and 4 (severe redness, inflammation, pain, oedema), (Surbhi, 2011). The fractures were classified based on bone involved, type of fracture and diaphyseal location using cranio-caudal and medio-lateral radiographic projections (Unger *et al.,* 1990).

Intra-operatively, duration of surgery, extent of manipulation, size of bone plate used, intra-operative stability of fixation, degree of ease/technical difficulty in application and complications, if any, were recorded. Fracture healing was assessed using orthogonal radiographs and postoperative weight bearing, assessed every 1 to 2 weeks from 5th to 6th week postoperatively using a scoring system as reported by Surbhi (2011). Posture was scored as 1 (carrying the limb off the ground), 2 (touching the toe on the ground) and 3 (touching the paw on the ground). Gait of the dogs while walking and running was scored as 1 (carrying the limb off the ground), 2 (occasional touching the toe/paw onto the ground), 3 (frequent touching the toe and paw onto the ground), 4 (touching the toe on every step onto the ground) and 5 (touching the paw on every step onto the ground), (Surbhi, 2011). The scoring was done by the same observer who was unaware of the plate-screw configuration adopted for fixation. Perception of pain in the extremity was scored by palpation and manipulation as 1 (no pain response on limb manipulation), 2 (mild, allows limb manipulation through normal range of motion, but acknowledges pain by turning head or pulling away), 3 (moderate, will not allow manipulation through normal range of motion; acknowledges pain as in score 2) and 4 (severe, will not allow limb manipulation), (Cross *et al*., 1997).

Preoperatively and at 11^{th} to 12^{th} postoperative week, lameness and functional recovery were scored. Lameness was scored as 1 (no observable lameness), 2 (intermittent mild weight bearing lameness with little or if any change in gait), 3 (consistent mild weight bearing lameness with little change in gait), 4 (moderate weight bearing lameness, obvious lameness with noticeable "head-bob" and change in gait), 5 (severe weight bearing lameness "toe-touching" only) and 6 (non-weight bearing lameness), (Cook *et al.*, 1999). Functional recovery was scored as 'very good' (normal fracture healing with normal leg usage), 'good' (normal fracture healing but slight lameness persisting), 'satisfactory' (fracture healing with delayed union leading to apparent lameness) and 'unsatisfactory' (fracture failed to heal due to fixation failure or infection), (Kumar, 2007). Rotational defects of the distal limb were graded as being either present or absent. Fracture healing, as assessed through orthogonal radiographs, was based on criteria such as loss of sharp fracture edges, loss of fracture line, cortical continuity, presence of callus, presence or absence of primary and secondary reduction loss, delayed union, non-union, and osteomyelitis (Sirin *et al*., 2013). Measurements of fracture angulations between fragments in the sagittal and coronal planes was done on cranio-caudal and medio-lateral radiographic projections immediately after surgery and on the 11^{th} to 12^{th} week postoperative follow-up. Postoperative complications, if any, were also recorded. Photographic and video graphic evaluation of the affected limb was done during follow-up presentations to record any apparent conformational changes in the limbs and to assess the weight bearing. Long term follow-up (> 4 months) information was obtained *via* telephonic conversation from all the clients. Client opinions and assessment of the outcome were recorded as satisfied, unsatisfied, indifferent or uncertain (Reems *et al*., 2003).

Statistical analysis: The data was analyzed statistically using SPSS software version 22.0 (SPSS, Inc., Chicago, IL). Summary statistics (Mean ± SE, median ± SE and range) were calculated for all variables. Independent samples *t* test was used to compare the parametric data at different time intervals between the groups. The non-parametric data generated from the scoring were analysed using Mann-Whitney U test and Wilcoxon sign rank test. Mann-Whitney U test were used to check for significance between the groups at corresponding time intervals and Wilcoxon sign rank test was used to compare them at different time intervals to their respective baseline values within a group.

RESULTS

Twelve intact dogs referred for simple transverse diaphyseal fractures of long bones such as femur, tibia, humerus and radius were randomly assigned to each group. The age, body weight, sex, time elapsed at the time of presentation, type of fracture, bone involved, side affected, location of diaphysis involved and preoperative soft tissue status of the affected region are shown in table 1. There was no significant difference ($P>0.05$) with respect to age, body weight, time elapsed at the time of presentation and preoperative soft tissue status scores between the groups. The surgical procedure was successful in all the patients. Good intra-operative stability was obtained in all instances after fixation of bone plates with either screw-cortex configurations. In both groups, fragments were easily reduced in 5 (5/6) cases each, with moderate difficulty in reduction observed in overriding humeral fractures. Bicortical screw placement necessitated meticulous depth measurements for selection of exact lengths of screws to avoid prominence of screw, damage to vasculature and flexor/extensor *in situ*, especially in bones of lower limbs. During placement of unicortical screw in group B, accidental stripping of the *trans*-cortex was observed on subsequent radiographic evaluation in dog B-5. The Mean ± SE duration of surgery in group B was significantly shorter ($P\leq0.05$) than group A (Table 2). The anaesthetic recovery was uneventful in all the cases.

The median stance and gait scores during standing, walking and running on the day of presentation were 0.00 ± 0.17, 0.00 ± 0.17 and 0.00 ± 0.00, respectively, in group A and 0.00 ± 0.21, 0.00 ± 0.21 and 0.00 ± 0.00, respectively, in group B. The scores on the 5^{th} to 6^{th} week, 8^{th} to 9^{th} week and 11^{th} to 12^{th} week did not show any significant difference ($P>0.05$) between the groups, while a decline in median scores was observed in group B, owing to complications (Table 3). Standing scores were found to be higher than the walking and running scores at corresponding intervals in both groups (Table 3). Early weight bearing and limb function were observed in all the dogs by 2nd postoperative week. Pain on palpation and manipulation decreased significantly ($P \leq 0.05$) in both groups in parallel to one another. However, there was no significant difference ($P > 0.05$) between the groups (Table 4). Lameness scores did not differ significantly ($P > 0.05$) between the groups during the 12th postoperative week (Table 4).

Primary gap healing was seen in both groups with minimal or no callus formation and slow disappearance of the fracture line. Radiographs on 5th to 6th postoperative week revealed small periosteal bridging callus at the *cis*-cortex without any signs of callus at the *trans*-cortex and an evident radiolucent fracture line. During 8th to 9th postoperative week, radiographs showed bridging callus of minimal size and fading of fracture line, indicating rigid fixation. Complete disappearance of fracture line with cortical continuity was observed on radiographs taken at 11th and 12th week, postoperatively [Fig. 2, 3, 4 and 5]. The Mean ± SE radiographic healing time in group A was non-significantly lower ($P > 0.05$) than in group B (Table 2). Age of the dog, body weight, time lapsed at the time of presentation and duration of surgery had no significance ($P > 0.05$) on the fracture healing time. There was no significant difference ($P > 0.05$) between groups A and B in terms of either sagittal or coronal plane fracture angulation over both immediate post-operative and the 11th to 12th postoperative week on orthogonal radiographic projections (Table 2). The variations in angulations on orthogonal radiographic projections within the groups between the immediate postoperative and the 11th to 12th postoperative week, were associated with the major complications that occurred in dogs A-1, B-3 and B-4 and minor complications in dogs A-3 and B-1, respectively.

The functional recovery in group A was graded as very good in 4 cases, satisfactory in 1 and unsatisfactory in 1 case. In group B, the functional recovery was graded as very good in 3 cases, good in 1 and unsatisfactory in 2 cases. Major postoperative complications were noticed in one dog of group A and two dogs of group B, after an initial progression to complete weight-bearing at 4th week. The complications included complete breakage of implant in dog A-1, dislodgement of the plate with breakage of the head of the far bicortical screw and pull-out of the adjacent unicortical screw in dog B-3 and *enbloc* screw pull-out from the proximal fragment in dog B-4. Minor complications included slight secondary angulations of bone fragments in dogs A-3 and B-1. A retrospective evaluation of the failures ruled out the possible involvement of the cortex-screw configuration in the development of complications [Fig. 6]. The client's compliance with postoperative care and assessment of outcomes are shown in table 5. Absence of client's compliance with post-operative movement restriction was seen in 25% of cases.

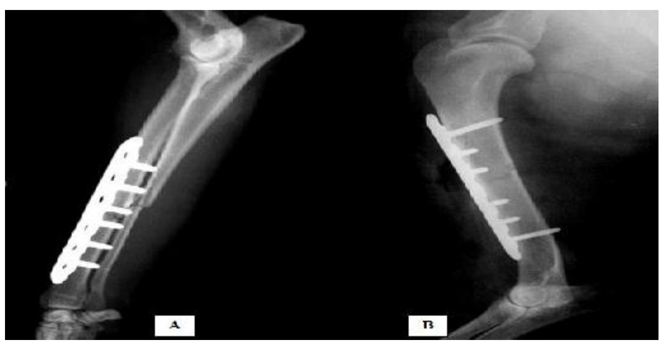

Figure 1. Radiographs depicting screw configurations of group A (A) and group B (B) in dogs A-6 and B-6, respectively

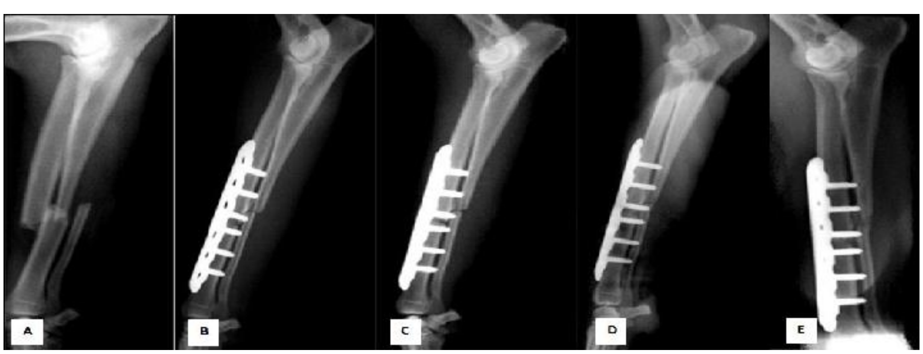

Figure 2. Medio-lateral radiographic projection of radius-ulna of dog A-6 on day of presentation (A), immediate postoperative (B), on 5th postoperative week (C), on 8th postoperative week (D) and on 11th postoperative week (E)

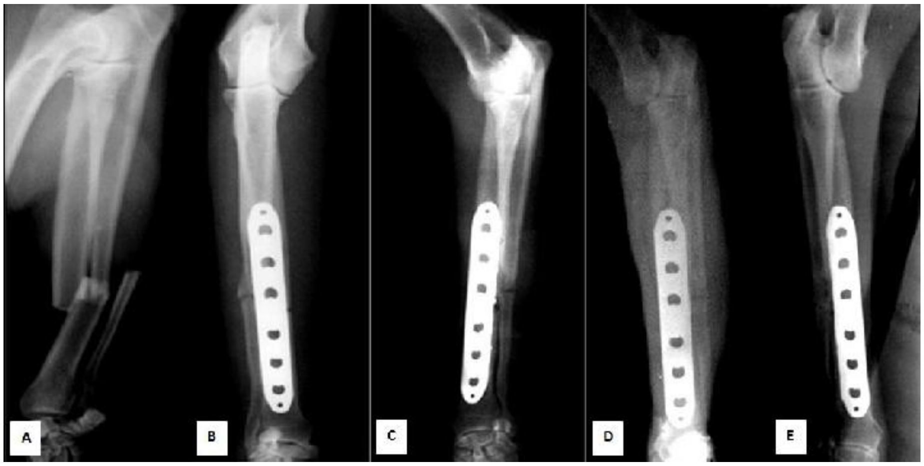

Figure 3: Cranio-caudal radiographic projection of radius-ulna of dog A-6 on day of presentation (A), immediate postoperative (B), on 5th postoperative week (C), on 8th postoperative week (D) and on 11th postoperative week (E)

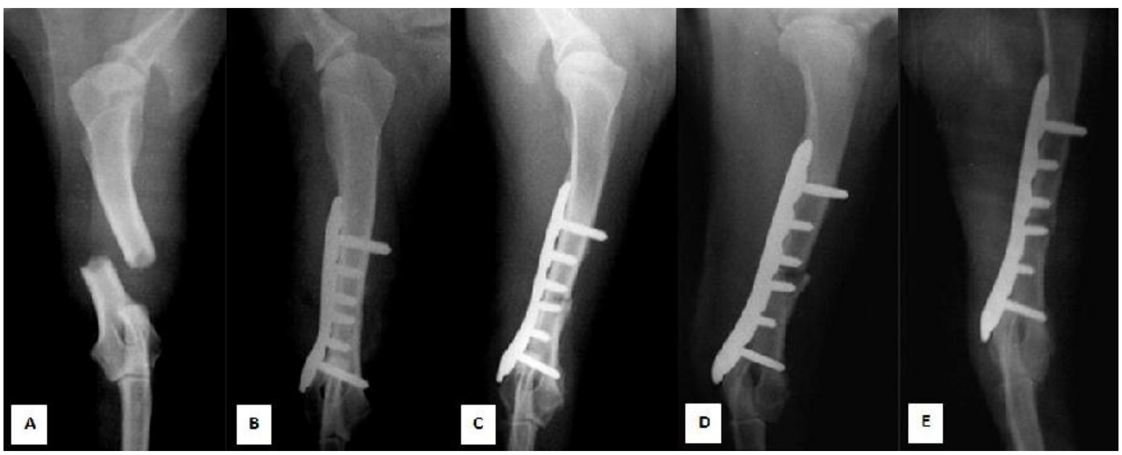

Figure 4: Cranio-caudal radiographic projection of humerus of dog B-5 on day of presentation (A), immediate postoperative (B), on 6th postoperative week (C), on 9th postoperative week (D) and on 12th postoperative week (E)

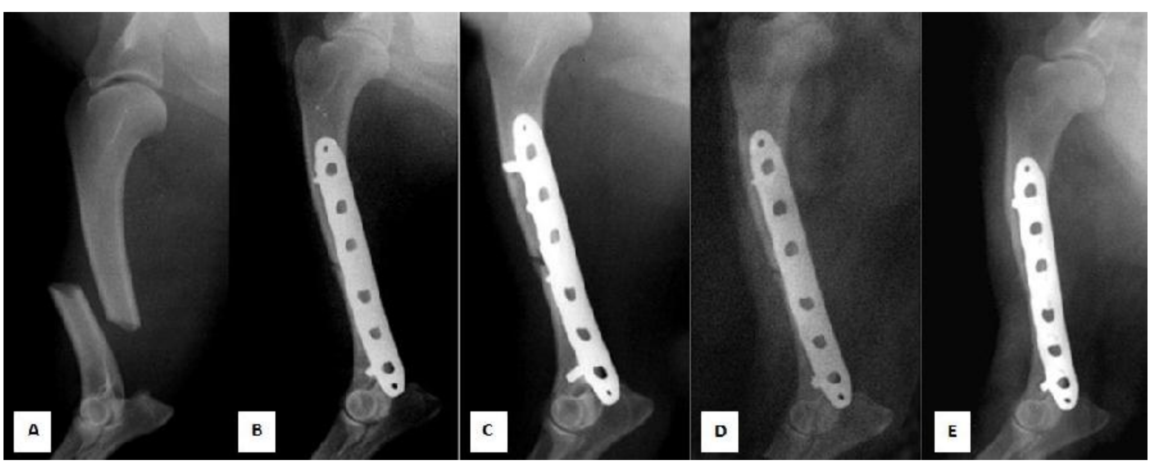

Figure 5: Medio-lateral radiographic projection of humerus of dog B-5 on day of presentation (A), immediate postoperative (B), on 6th postoperative week (C), on 9th postoperative week (D) and on 12th postoperative week (E)

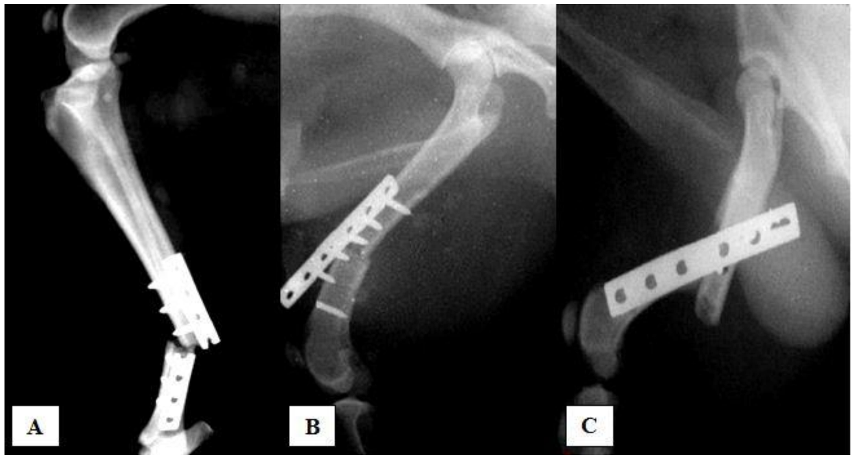

Figure 6: A. Breakage of locking plate in dog A-1, B. Dislodgement of plate with breakage of head of far bicortical screw and pull-out of adjacent unicortical screw in dog B-3 and C. *Enbloc* screw pull-out from proximal fragment in dog B-4

Table 1. Grouping of cases, fracture class and preoperative soft tissue status.

Dog No.	Age (Months)	Breed	Sex	Bwt (Kg)	Time lapsed (days)	Etiology	Fracture type	Bone affected (side affected)	Unger's class	Soft tissue score	Plate size (mm)
A-1	84	Indian Spitz	M	14	1	Fall	ST	T&F (R)	42A3	1	2.7
A-2	96	Indian Spitz	M	8	1	Fall	SSO	T&F (R)	42A2	2	2.7
A-3	96	Indian Spitz	M	18	3	Abuse	ST	H (R)	12A3	1	3.5
A-4	7	Indian Spitz	M	7	4	Fight	SSO	F (R)	32A2	1	2.7
A-5	7	Labrador Retriever	M	17	3	Fall	ST	F (L)	32A3	1	2.7
A-6	48	Nondescript	M	14	1	Fall	ST	R&U (R)	22A2	2	3.5
Mean/ Median ± SE	56.33 ± 17.17	-	-	13.0 ± 1.86	2.17 ± 0.54	-	-	-	-	1.00 ± 0.52	-
B-1	12	Nondescript	M	14	1	Accident	ST	F (L)	32A3	1	2.7
B-2	18	Indian Spitz	M	12	3	Abuse	ST	R&U (R)	22A2	1	2.7
B-3	30	Indian Spitz	M	13	1	Fall	ST	F (L)	32A3	2	2.7
B-4	30	Chinese pug	M	9	0	Fall	ST	F (R)	32A3	1	2.7
B-5	84	Indian Spitz	M	12	2	Accident	ST	H (R)	12A3	1	3.5
B-6	16	German Shepherd	M	30	2	Accident	SSO	H (R)	12A2	2	3.5
Mean/ Median ± SE	31.67 ± 10.89	-	-	15.0 ± 3.07	1.50 ± 0.43	-	-	-	-	1.00 ± 0.52	-

M: Male, F: Female; ST: Simple transverse, SSO: Simple short oblique; T&F: Tibia and fibula, H: Humerus, F: Femur, R&U: Radius and Ulna; R: Right, L: Left

Table 2. Mean values of duration of surgery, radiographic observations on fracture healing time and angulation.

Group	Surgery duration (min.)	Radiographic healing time (days)	Angulations in sagittal plane		Angulations in coronal plane	
			0	3	0	3
A	57.17 ± 2.73^{a}	63.00 ± 3.00	0.67 ± 0.67^{a}	4 ± 2.92^{b}	0.5 ± 0.5^{a}	2.6 ± 1.94^{b}
B	48.00 ± 2.94^{b}	80.00 ± 13.78	1.5 ± 0.96^{a}	6.6 ± 4.69^{b}	0.5 ± 0.5^{a}	6.2 ± 3.47^{b}

0: Observation on first day of presentation, 3: Observation on 11^{th} to 12^{th} week; $^{a\&b}$differ significantly ($p \leq 0.05$)

Table 3. Median weight bearing scores during standing, walking and running.

Group	Weight bearing while standing			Weight bearing while walking			Weight bearing while running		
	1	2	3	1	2	3	1	2	3
A	2.00 ± 0.40	2.00 ± 0.20	2.00 ± 0.20	4.00 ± 0.58	4.00 ± 0.60	4.00 ± 0.40	4.00 ± 0.58	4.00 ± 0.60	4.00 ± 0.60
B	2.00 ± 0.49	2.00 ± 0.40	2.00 ± 0.40	3.00 ± 0.81	3.00 ± 0.81	3.00 ± 0.75	3.00 ± 0.81	3.00 ± 0.81	3.00 ± 0.75

1: Observation on 5^{th} to 6^{th} week, 2: Observation on 8^{th} to 9^{th} week, 3: Observation on 11^{th} to 12^{th} week

Table 4. Median postoperative pain and lameness scores.

Group	Pain scores				Lameness scores	
	0	1	2	3	0	3
A	4.00 ± 0.00^a	1.00 ± 0.40^b	1.00 ± 0.20^b	1.00 ± 0.20^b	5.00 ± 0.17^a	0.00 ± 0.60^b
B	4.00 ± 0.00^a	1.00 ± 0.40^b	1.00 ± 0.24^b	1.00 ± 0.20^b	5.00 ± 0.21^a	1.00 ± 0.75^b

0: Observation on first day of presentation, 1: Observation on 5^{th} to 6^{th} week, 2: Observation on 8^{th} to 9^{th} week, 3: Observation on 11^{th} to 12^{th} week; $^{a\&b}$differ significantly ($p \leq 0.05$)

Table 5. Client compliance with post-operative care and their assessment of outcome.

Dog No.	Functional recovery	Compliance with post-operative care	Client's assessment of outcome
A-1	Unsatisfactory	Complaint	Unsatisfied. Satisfied after fixation and subsequent uneventful healing
A-2	Very good	Complaint	Satisfied. Delayed healing of incision site. Requested early plate removal
A-3	Satisfactory	Non-complaint with movement restriction	Satisfied with early weight bearing
A-4	Very good	Complaint	Satisfied with early weight bearing
A-5	Very good	Complaint	Satisfied with early weight bearing
A-6	Very good	Partially complaint with movement restriction	Satisfied with early weight bearing
B-1	Good	Non-complaint with movement restriction	Satisfied. Concern on occasional pain
B-2	Very good	Complaint	Satisfied with early weight bearing
B-3	Unsatisfactory	Non-complaint with movement restriction	Unsatisfied. Refused re-fixation to correct secondary loss of reduction
B-4	Unsatisfactory	Complaint	Unsatisfied. Satisfied after re-fixation and subsequent uneventful healing
B-5	Very good	Complaint	Satisfied with early weight bearing
B-6	Very good	Complaint	Satisfied with early weight bearing

DISCUSSION

The ability of locking plates in framing osteosynthesis has evolved them as effective tool in the armamentarium of orthopaedicians. Locking compression plates (LCPs) have already been established in clinical practice with several complex osteosynthesis principles. Although the multifaceted locking plates assure versatile screw combinations, the choice of effective screw-cortex configurations for optimum use in a variety of clinical cases is a subject of debate. Unlike dynamic compression plates (DCPs), where screws are placed without locking with plate holes, locking plates utilize LHS that locks with the plate holes. Locking plates also have dynamic holes that enables eccentric placement of screws wherever compression between bone fragments is necessary as in DCP. Since DCP hole lacks locking facility, bicortical placement of screws is obligatory for adequate fixation and to prevent screw pull out from bony cortex, while it is seldom necessary with locking plates. The advantages of unicortical screw placement for plate fixation over bicortical placement in biological osteosynthesis are well-known (Dona *et al*., 2004; Goh *et al*., 2009; Overturf *et al*., 2014 and Pater *et al*., 2014). Our deliberation was that unicortical placement of locking screws towards the fracture line, except at the distal holes, may be sufficient enough for adequate fracture fixation, weight loading and fracture healing.

Only simple transverse or short oblique diaphyseal fractures of long bones were selected for the study, since inter-fragmentary compression in these cases, was hardly required; furthermore, inter-fragmentary compression could easily be achieved with reduction and holding forceps. Two different sized plates, 2.7mm and 3.5mm, either 6 hole or 7 hole, were used as the array of long bones selected for the study fit in these dimensions. To provide adequate stiffness and to maintain the reduced fragments under compression, a short working length was used (Nanavati and Walker, 2014). Adequate bone-plate distance could be maintained with both screw-cortex configurations without compressing the periosteum and this ability is inherent to locking plates (Haaland *et al*., 2009). In contrast to conventional screws, LHS do not provide sufficient tactile feedback of complete screw tightening (Boudrieau, 2016). We lacked a torque-limited semi-automated screwdriver and hence additional attention was needed to ensure proper screw seating. In order to maintain homogeneity, cases in our study underwent plate fixation with 3 locking screws on either fragment with 2 of them right beside the fracture line, which led to elimination of many cases from the study. A similar configuration has been tested successfully in previous biomechanical studies (Lee *et al*., 2014 and Nourisa *et al*., 2015). Good intra-operative stability was achieved after fixation with either screw-cortex configuration indicating the adequacy of both techniques. The significant decrease in duration of surgery required in unicotical-bicortical screw-cortex configuration technique may be attributed to the need to drill through *cis*-cortex alone, sparing *trans*-cortex and depth measurement.

All dogs that underwent surgery showed implant loaded weight bearing by the 2nd postoperative week without any apparent joint stiffness, rotational deformities or muscle atrophy. Early weight bearing was due to the inherent plate-bone construct stability irrespective of screw-cortex configuration (El-Husseiny *et al.,* 2012). Previous clinical studies using LCP has also reported complete weight bearing and limb function during the 2nd postoperative week (El-Husseiny *et al.,* 2012). Full weight loading may be allowed in 1mm gap transverse fractures fixed with a LCP (Kanchanomai *et al.*, 2010). However, we did not attempt an evaluation of implant loading by walking and running during the 2nd postoperative week, in case it interfered with postoperative recovery process, including constructs stability and fracture healing. This could be supported from the findings of Kanchanomai *et al.* (2008), who reported fatigue failures of LCP, during full load of walking, before adequate fracture healing in transverse fractures of 8mm gap. Steady improvement in standing, walking and running scores during subsequent intervals from 5th postoperative week indicated reduction in pain and increased inter-fragmentary stability. These findings attributed to adequate fracture reduction and load sharing. Walking and running scores were found to improve almost parallel to each other, with an overall marginally faster improvement in walking scores.

Postoperative pain scores improved along with weight bearing scores during subsequent time intervals. Pain scale used by Sirin *et al*. (2013) for evaluating postoperative pain after LCP fixation in 32 dogs was used in our study. In fact, the scale does not directly evaluate pain, but uses lameness as an indicator of pain (Hudson *et al*., 2004**)**. The fracture healing time was acceptable with both configurations, comparable to the previous findings (Sirin *et al*., 2013 and Haaland *et al*., 2009). Hence, it should be assumed that both the screw-cortex configurations were adequately rigid as the fracture healed by primary gap healing which is an indication of little or no mechanical instability. Since the fixation was stable, the size and width of callus formed was less (Beale, 2004). Secondary healing associated with slightly flexible buttress fixation in simple transverse fractures (Ramesh, 2011 and Sirin *et al*., 2013) and in fracture gap less than 1mm (Miller and Goswami, 2007) has also been reported. In our study, primary healing was consistent with both the cortical-screw configurations in spite the screws adjacent to the fracture line were placed in neutralization mode. The healing phenomenon represented the normal pattern of early bony resorption of fracture edges, which contributed to inter-fragmentary strain reduction allowing new bone formation and restoration of cortical continuity. The screw-cortex configuration did not significantly affect the healing time. The difference in mean healing times between the groups may be attributable to the cases that faced complications in group B. Primary and secondary angulation between fracture fragments was minimal and within acceptable limits for bone healing, as envisaged by Malkawi *et al*. (1986).

Functional recovery on the 11th to 12th postoperative week was graded excellent (66.7%) in both the groups and poor in 16.6% of the fractures repaired. The functional recovery was influenced by the fixation stability alone irrespective of screw-cortex configuration and placement, alongside the implant biomechanics. An overall major complication rate of 25% was seen in our study that is considerably higher compared to previous studies, owing to the less number of cases in each group. Fixation failure rates as high as 5-18% in diaphyseal fractures have been reported previously (Sommer *et al*., 2003; Sommer *et al*., 2004 and Haaland *et al*., 2009).

A retrospective evaluation of those cases with implant failure ruled out the possible involvement of screw-cortex configuration adopted in the study. Rather, the failures may be attributed to the use of inappropriately sized plates coupled with the short plate working length and high screw density. The fractures selected for our study being simple transverse or short oblique, we adopted a short working length in order to provide adequate stability and stiffness, and to maintain the reduced fragments under compression. In both the groups, the failures occurred with 2.7mm locking plates. No significant variation was observed in the cross-section of 2.7mm locking plates (Nebula Surgical Private Limited, Gujarat, India), which were used in the study, from that of LCP marketed by the Synthes, Switzerland. Although the size of plate was selected based on guidelines for conventional plating, a 3.5mm plate would have possibly withstood sharing load for a longer period of time and might have been a better choice for dogs A-1 and B-3, considering the rigidity and stiffness of fixation. Plate breakage occurred at the DCU (Dynamic Compression Unit) of the empty plate hole overlying the fracture site in dog A-1. The DCU is susceptible to breakage if exposed to increased stress and strain concentration, especially with smaller cross section plates (Stoffel *et al*., 2003 and Smith *et al*., 2007). A short working length in addition to the smaller cross section of plate might have caused stress concentration in the implant, and when the movement between the main fragments was too great, the plate might have eventually fatigued (Sommer *et al*., 2004 and Haaland *et al*., 2009). Even, fatigue failure of LCP, fixed for transverse fractures, during full loading in the early postoperative period has been biomechanically established (Kanchanomai *et al.*, 2008). After failure, it was difficult to remove the distal screw from the plate due to cold fusion or welding between the LHS and plate hole. This phenomenon has been recognised previously by Smith *et al*. (2007), Steven and ten Duis (2008), Cronier *et al*. (2010) and Azboy *et al*. (2013).

The reason for the screw breakage in case B-3 could be due to defective screw or overloading. Screw breakage occurred directly under the screw head near the screw-plate interface and is often a common point of breakage (Boudrieau, 2016). Sirin *et al*. (2013) reported a broken LHS attributed to a defective screw. Breakage occurs in case of chronic instability or increased strain as a result of rotational forces (Smith *et al*., 2007). The broken screw was in bicortical configuration. In fact, in LCP, the load is transferred equally to all screws in a fragment (Gardner *et al*., 2006). Hence, the instability or inability of unicortical screws to share the load equally, that could lead to stress concentration in the sole bicortical screw, is questionable. Further, the size and length of the plate used for fixation was thought to be insufficient. The load sharing across the implant would have been better if a longer plate was used (Stoffel *et al*., 2003). *Enbloc* screw pull-out from the proximal fragment was seen in an active Pug after skidding on sand with a sudden jerk during the 4th postoperative week. It is a normal mode of failure of LCPs since the strength of fixation with these plates is equal to the strength of all the screw-bone interfaces (Gardner *et al.*, 2006; Smith *et al*., 2007; Haaland *et al*., 2009 and Niederhauser *et al*., 2015). Although the pullout strength of unicortical screws are only about 70% of that of bicortical screws (Smith *et al*. 2007), the failure was attributed to an accident during the postoperative period owing to sudden overloading. Catastrophic failure may be more likely with unicortical LHS use in small animal patients in a fully loaded bone (Boudrieau, 2016).

Apart from the potential implant failure, other major complication such as non-union, delayed union and osteomyelitis were not observed in our study. Minor complications similar to those reported by Haaland *et al*. (2009) were also not observed. Complications associated with prominence of screw outside the *trans*-cortex were not observed in either group, though in case A-4, perceptible periosteal callus was present around all the bicortical screw tips. Hence, the theoretical advantage in terms of absence of screw prominence of unicortical screws, as compared to bicortical screws was not discernible. Slight stripping of *trans*-cortex during placement of longer unicortical screws was observed in dog A-5, as often occurs during unicortical screw placement (Miller and Goswami, 2007).

Contradictory reports on the use of locking plates in single bone shaft fractures exist. Non-union has been recognized as an adverse outcome due to the combination of a stiff plate, stiff screws, and fracture distraction (Smith *et al*., 2007). In simple transverse fractures, inter-fragmentary compression with at least one eccentric screw has been advised while using locking plates (Miller and Goswami, 2007 and Azboy *et al*., 2013). To evaluate the screw-cortex configuration, we attempted fixation of plate in neutral locking mode rather than in dynamic form, as compression was found seldom necessary after reduction of the fragments. Fixation by locking plates has been successfully used with or without inter-fragmentary compression in osteotomised tibia of sheep, leading to the same results (Plecko *et al*., 2012).

The 25% non-compliance rate combined with active patients seen in the current clinical study, demonstrates a veterinary clinical scenario against which any technique ought to be refined before widespread use. In terms of low rate of screw-related complications, the bicortical screw configuration was superior to the mixed screw-cortex configuration despite the fact that the failures were not associated with screw-cortex configuration. The discernible advantage of mixed screw-cortex configuration noted in the present study was ease of application, which shortened the duration of surgery. The findings substantiated the hypothesis that fixation of locking plates using unicortical-bicortical screw configuration provide adequate stability and enable fracture healing similar to bicortical screw configuration in simple diaphyseal long bone fractures in dogs. Comprehensive clinical studies in a larger case pool are warranted prior to regular utilization of configurations involving unicortical locking screws.

Author's declaration of interest: Authors have no conflict of interest.

Source of funding: The investigation was funded by the ICAR-Indian Veterinary Research Institute, Izzatnagar, Bareilly, Uttar Pradesh, India.

Acknowledgements: The author acknowledge the scholars, scientific and technical staff of Division of Surgery and Teaching Veterinary Clinical Complex and Referral Veterinary Polyclinic, ICAR-Indian Veterinary Research Institute, Izzatnagar, Bareilly, Uttar Pradesh, India for providing necessary support and help at various level for the study.

Authorship: Nitish Kallianpur wrote the manuscript. Aswathy Gopinathan and Kiranjeet Singh contributed to the conception and design of study. Sherin B. Sarangom and Pallvi Sharma made critical revision of data analysis and manuscript. C. Sowbharenya and Christina John made substantial contribution to acquisition, analysis and interpretation of data. All the authors made substantial contribution to surgical interventions, further revision of manuscript and its final approval.

REFERENCES

Azboy, I., A. Demirtas, B. Y. Ucar, M. Bulut, C. Alemdar and E. Ozkul (2013). Effectiveness of locking versus dynamic compression plates for diaphyseal forearm fractures. Orthopedics. 36(7): 917-922.

Beale, B. (2004). Orthopedic clinical techniques femur fracture repair. Clin. Tech. Small Anim. Pract. 19(3): 134-150.

Boudrieau, R. (2016). Complications specific to locking plates. In: Griffon, D. and A. Hamaide, eds. Complications in small animal surgery. Wiley-Blackwell, Ames, Iowa. pp. 714-24.

Cook, J. L., J. L. Tomlinson and A. L. Reed (1999). Fluoroscopically guided closed reduction and internal fixation of fractures of the lateral portion of the humeral condyle: prospective clinical study of the technique and results in ten dogs. Vet. Surg. 28(5): 315-321.

Cronier, P., G. Pietu, C. Dujardin, N. Bigorre, F. Ducellier and R. Gerard (2010). The concept of locking plates. Orthop. Traumatol. Surg. Res. 96(4): 17-36.

Cross, A. R., S. C. Budsberg and T. J. Keefe (1997). Kinetic gait analysis assessment of meloxicam efficacy in a sodium urate-induced synovitis model in dogs. Am. J. Vet. Res. 58(6): 626-631.

Dona, E., R. M. Gillies, M. P. Gianoutsos and W. R. Walsh (2004). Plating of metacarpal fractures: unicortical or bicortical screws? J. Hand Surg. Br. 29(3): 218-221.

Dunlap, J. T., G. L. Lucas, A. C. Chong, F. W. Cooke and V. Tiruvadi (2011). Biomechanical evaluation of locking plate fixation with hybrid screw constructs in analogue humeri. Am. J. Orthop. 40(2): 20-25.

El-Husseiny, I, N., M. B. Mostafa, M. B. El-Habak, and H. F. Harb (2012). Biomechanical studies on femoral fracture repair fixed by different fixation methods in dogs. J. Am. Sci. 8(1): 216-222.

Gardner, M. J., M. H. Griffith, D. Demetrakopoulos, R. H. Brophy, A. Grose, D. L. Helfet and D. G. Lorich (2006). Hybrid locked plating of osteoporotic fractures of the humerus. J. Bone Joint Surg. Am. 88(9): 1962-1967.

Goh, C. S., B. G. Santoni, C. M. Puttlitz and R. H. Palmer (2009). Comparison of the mechanical behaviors of semicontoured, locking plate-rod fixation and anatomically contoured, conventional plate-rod fixation applied to experimentally induced gap fractures in canine femora. Am. J. Vet. Res. 70(1): 23-29.

Haaland, P. J., L. Sjostrom, M. Devor and A. Haug (2009). Appendicular fracture repair in dogs using the locking compression plate system: 47 cases. Vet. Comp. Orthop. Traumatol. 22(4): 309-315.

Hudson, J. T., M. R. Slater, L. Taylor, H. M. Scott and S. C. Kerwin (2004). Assessing repeatability and validity of visual analogue scale questionnaire for use in assessing pain and lameness in dogs. Am. J. Vet. Res. 65(12): 1634-1643.

Johnson, A. L. (2013). Fundamentals of orthopedic surgery and fracture management. In: Fossum, T. W. ed. Small animal surgery. 4th edition, Elsevier Moseby, St. Louis, Missouri. pp. 1033-1105.

Kanchanomai, C., P. Muanjan and V. Phiphobmongkol (2010). Stiffness and endurance of a locking compression plate fixed on fractured femur. J. Appl. Biomech. 26(1): 10-16.

Kanchanomai, C., V. Phiphobmongkol and P. Muanjan (2008). Fatigue failure of an orthopedic implant - A locking compression plate. Eng. Fail. Anal. 15(5): 521-530.

Koch, D. (2005). Screws and plates. In: Johnson, A. L., J. Houlton and R. Vannini, eds. AO Principles of Fracture Management in the Dog and Cat. AO Publishing, Davos Platz, Switzerland. pp. 27-51.

Kumar, P. (2007). Studies on the occurrence and management of compound fracture using epoxy pin/metallic linear and circular external skeletal fixation devices in animals. MVSc thesis, ICAR-Indian Vet. Res. Institute, Izatnagar, India.

Lee, C. H., K. S. Shih, C. C. Hsu and T. Cho (2014). Simulation-based particle swarm optimization and mechanical validation of screw position and number for the fixation stability of a femoral locking compression plate. Med. Eng. Phys. 36(1): 57-64.

Malkawi, H., A. Shannak and S. Hadidi (1986). Remodeling after femoral shaft fractures in children treated by the modified blount method. J. Pediatr. Orthop. 6(4): 421-429.

Miller, D. L. and T. Goswami (2007). A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing. Clin. Biomech. 22(10): 1049-1062.

Nanavati, N. and M. Walker (2014). Current concepts to reduce mechanical stiffness in locked plating systems: a review article. Orthop. Res. Rev. 6: 91-95.

Niederhauser, S. K., S. Tepic and U. T. Weber (2015). Effect of screw position on single cycle to failure in bending and torsion of a locking plate-rod construct in a synthetic feline femoral gap model. Am. J. Vet. Res. 76(5): 402-410.

Nourisa, J., A. Baseri, L. Sudak and G. Rouhi (2015). The effects of bone screw configurations on the interfragmentary movement in a long bone fixed by a limited contact locking compression plate. J. Biomed. Sci. Eng. 8(9): 590-600.

Overturf, S. J., R. P. Morris, Z. Gugala and R. W. Lindsey (2014). Biomechanical comparison of bicortical locking versus unicortical far-cortex-abutting locking screw-plate fixation for comminuted radial shaft fractures. J. Hand. Surg. Am. 39(10): 1907-1913.

Pater, T. J., S. I Grindel, G. J Schmeling and M. Wang (2014). Stability of unicortical locked fixation versus bicortical non-locked fixation for forearm fractures. Bone Res. 2: 14014.

Plecko M, N. Lagerpusch, B. Pegel, D. Andermatt, R. Frigg, R. Koch, M. Sidler, P. Kronen, K. Klein, K. Nuss, P. Gedet, A. Burki, S. J. Ferguson, U. Stoeckle, J. A. Auer and B. Von Rechenberg (2012). The influence of different osteosynthesis configurations with locking compression plates (LCP) on stability and fracture healing after an oblique 45° angle osteotomy. Injury. 43(7): 1041-1051.

Ramesh, R. (2011). Locking Plate System for the management of unstable diaphyseal, metaphyseal fractures of femur, humerus and radius in dogs. PhD thesis, Tamil Nadu Vet. Anim. Sci. Univ. Chennai, India.

Ramesh, R., S. Ayyappan, R. Jayaprakash and G. Ramesh (2015). Open reduction and internal fixation with linear Locking Compression Plates for the stabilisation of unstable diaphyseal fracture of femur in dogs. Indian J. Vet. Anim. Sci. Res. 44(1): 36-41.

Reems, M. R., B. S. Beale and D. A. Hulse (2003). Use of a plate-rod construct and principles of biological osteosynthesis for repair of diaphyseal fractures in dogs and cats: 47 cases (1994–2001). J. Am. Vet. Med. Assoc. 223(3): 330-335.

Roberts, J. W., S. I. Grindel, B. Rebholz and M. Wang (2007). Biomechanical evaluation of locking plate radial shaft fixation: unicortical locking fixation versus mixed bicortical and unicortical fixation in a sawbone model. J. Hand Surg. Am. 32(7): 971-975.

Sirin, S. O., U. Kaya and B. Olcay (2013). Clinical and radiological outcomes of Locking Compression Plate System in dogs with diaphyseal fractures: 32 Cases. Kafkas Univ. Vet. Fak. Derg. 19(Suppl A): 13-18.

Smith, W. R., B. H. Ziran, J. O. Anglen and P. F. Stahel (2007). Locking plates: tips and tricks. J. Bone Joint Surg. Am. 89(10): 2298-2307.

Sommer, C., E. Gautier, M. Müller, D. L. Helfet and M. Wagner (2003). First clinical results of the Locking Compression Plate (LCP). Injury. 34(Suppl 2): B43-54.

Sommer, C., R. Babst, M. Müller and B. Hansom (2004). Locking compression plate loosening and plate breakage: a report of four cases. J. Orthop. Trauma 18(8): 571-577.

Sommer, C., M. Schütz and M. Wagner (2007). Principles of the internal fixator. In: Rüedi, T. P., R. Buckley and C. G. Moran, eds. AO Principles of Fracture Management. Georg Thieme Verlag, Stuttgart, New York, p1103.

Stevens, C. T. and H. J. ten Duis (2008). Plate osteosynthesis of simple forearm fractures: LCP versus DC plates. Acta. Orthop. Belg. 74(2): 180-183.

Stoffel, K., U. Dieter, G. Stachowiak, A. Gachter and M. S. Kuster (2003). Biomechanical testing of the LCP-how can stability in locked internal fixators be controlled. Injury. 34(Suppl 2): B11-19.

Surbhi (2011). Studies on biomechanical and clinical studies on acrylic and epoxy-pin external skeletal fixation systems in dogs. PhD thesis, ICAR-Indian Vet. Res. Institute, Izatnagar, India.

Thakur, A. J. (2007). The elements of fracture fixation. 2nd Ed. Reed Elsevier, New Delhi, India, pp. 15-26.

Unger, M., Montavon, P. M. and U. F. A. Heim (1990). Classification of fractures of long bones in the dog and cat: introduction and clinical application. Vet. Comp. Orthop. Traumatol. 3(2): 5-14.

Wagner, M. (2006). General principles for the clinical use of the LCP. Injury. 34(Suppl 2): B31-42.