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RESEARCH ARTICLE ijvs

Determination of femoral neck angles and fabrication of Veterinary Barrel Plate system for stabilization of proximal femoral fractures in dogs

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The present study was conducted from November 2021 to October 2023 with the objective of determining implant-specific femoral neck angles and proximal femoral morphometric parameters in dogs, and utilising these data for the fabrication of the first-of-its-kind Veterinary Barrel Plate (VBP) system for the stabilisation of proximal one-third femoral fractures in dogs. Radiographic measurements of 270 femora from healthy dogs were obtained and categorised into three groups based on femoral length: small (n=72), medium (n=142), and large (n=56) dogs. The Veterinary Barrel Plate system was fabricated according to the morphometric measurements of medium-sized dogs. The developed implant effectively addressed the challenges associated with stabilisation of proximal one-third femoral fractures by plate osteosynthesis, including inherent instability, limited bone stock in the proximal fragment, and eccentric loading of the proximal femur.

Keywords: Dog, Femoral neck angle, Proximal femoral fracture, Veterinary Barrel Plate system

Fractures of the proximal femur account for approximately 25% of all femoral fractures and pose significant challenges for providing adequate internal fixation (Unger *et al.* 1990; Braden *et al.*, 1995; De Camp, 2016). Open reduction and internal fixation of proximal femoral fractures can be challenging because of several unique biological and mechanical features, including concurrent trauma to the fragile vascular network, residual growth potential of the capital physis, eccentric loading of the femoral head, limited bone stock for stabilization, and potential articular involvement.

Several implants have been used alone or in combination for subtrochanteric and proximal femoral diaphyseal fracture repair in dogs, including primary implants such as bone plates, interlocking nails, and external skeletal fixators and secondary implants such as intramedullary rods, Kirschner wires, lag screws, and cerclage wires (Simpson and Lewis, 2002). Stabilization of femoral neck fractures is usually performed using Kirschner wires, small-diameter Steinmann pins, and bone screws (Daly, 1978; Smith, 1985; Lambrechts *et al.*, 1993; Hulse and Hyman, 2003).

Plate osteosynthesis is usually the recommended method of fracture fixation (Johnston and Tobias, 2017) and requires placement of four or more bone screws (penetrating six–eight or more cortices) in each of the proximal and distal bone segments for fracture fixation (De Camp, 2016). The paucity of bone stock in the proximal fragment, acentric loading of the proximal femur, and inherent instability of the area pose a challenge for adequate stabilization by plate osteosynthesis. In addition, the available proximal femoral plates require contouring and extensive dissection of the soft tissues for placement of the plate lateral to the trochanter major for stabilization of proximal femur fractures (De Camp, 2016).

The variable anatomical features of canine femurs, such as shaft diameter, thickness of cortex, neck width, neck-shaft angle, depth of the trochanteric fossa, and biomechanical variation in load bearing during stance and ambulation, demand a unique implant that would cater to the various factors playing a key role in stabilization of proximal femoral fractures in canines. There is a paucity of literature regarding the availability of such implants in the treatment of proximal femoral fractures in dogs. In cases of proximal femoral fractures (proximal physeal, cervical, intertrochanteric, subtrochanteric, and proximal 1/3rd diaphyseal fractures), accurate measurements (general or implant-specific) of the dimensions of the proximal femur are useful in the selection and standardization of a suitable implant for optimal fracture fixation. Hence, the determination of radiographic measurements of femoral neck-shaft angles and implant-specific morphometry of small-, medium-, and large-sized dogs aided in designing suitable implants for adequate fixation of proximal femur fractures.

Considering the unavailability of a veterinary-specific implant for the management of proximal femoral and femoral neck fractures in dogs, the present study was undertaken to fabricate an implant specifically designed for the stabilization of these fractures.

Materials and Methods

The incidence and etiology of proximal femoral fractures were recorded during the study period. The

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Table 1: Average radiographic measurements in three groups of dogs.

Group	Length of femur (mm)	Neck width (mm)	Neck-shaft angle (°)	Length of barrel screw (mm)	Length of barrel (mm)
1	73.135	6.208	139.885	23.148	8.564
2	125.353	8.630	143.511	32.528	12.311
3	158.446	10.487	141.09	36.011	14.265

retrograde study of implant-specific radiographic morphometry of 250 proximal femurs of clinical cases presenting to the VCC was performed using Carestream Image suite software's built-in measuring tools (Fig. 1A and B). The measurements were divided and assigned to small (group I), medium (group II), and large (group III) dogs based on the length of the femur (Table 1). In addition, gross and radiographic measurements of 20 cadaver bones were taken to correlate with radiographic measurements and identify any differences in the measured values (Fig. 1C).

The Veterinary Barrel Plate (VBP) system was fabricated based on the average dimensions of group II, utilizing biocompatible 316 L stainless steel. The standardization of the implant and method was achieved through a cadaver study (Fig. 2) conducted under C-arm fluoroscopic guidance (Fig. 2C). The biomechanical study was conducted using an Instron Universal Testing Machine (UTM) with Bluehill model K-3369 software in a temperature range of 100-350 °C with a maximum load of 15 kN to determine the different properties of the bone, orthopaedic plate, and bone plate construct at the Central Institute of Plastics Engineering Technology, Chennai.

This study was approved by the Institutional Animal Ethics Committee (reference No. 281/go/ReBi/S/2000/CPCSEA/CVSc/007/Surgery/2022 dated 19.11.2022.

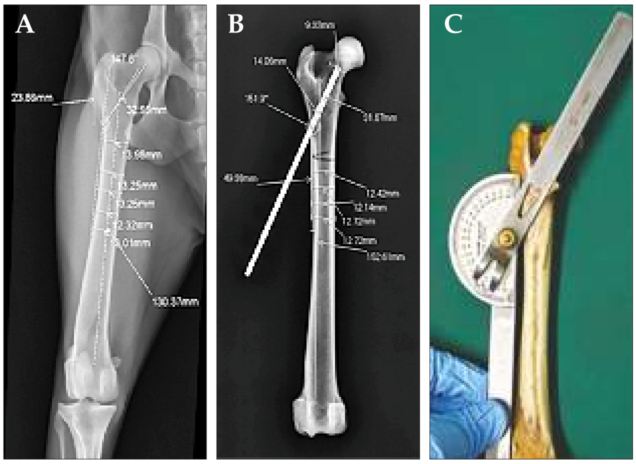

Fig. 1: Measurement of femur using Carestream Imagesuite' s inbuilt tools: (A) Radiographic measurements in a clinical case; (B) Radiographic measurements in cadaver femur; and (C) Gross measurement of neck-shaft angle in cadaver femur using goniometer.

Results and Discussion

During the study period, 87 cases of femoral fractures in dogs were recorded, of which 32 (36.7%) were proximal femoral fractures. Singh *et al*. (1983), Wong (1984), and Raouf *et al*. (2019) also reported a similar incidence of proximal femoral fractures. Among the proximal femur fracture cases recorded, the highest percentage (37.5%) was between 1-2 years of age, that is, after sexual maturity, which might be due to the seeking behaviour in dogs during sexual maturity. This was in accordance with Brinker (1965), Aparicio and Fjeld (1993), Braden *et al*. (1995), Aithal *et al*. (1999), Raghunath *et al*. (2007), Minar *et al*. (2013) and Talaat *et al*. (2022). In the present study, males were more affected (53%) than females (43%). This might be attributed to the behavioural differences between the sexes (Simon *et al*., 2010), that is, the tendency of males to wander around, making them prone to accidents and fractures (Aithal *et al*., 1999), and the tendency of female dogs to stay inside houses compared to male dogs (Raghunath *et al*., 2007). Similar results have been reported by Brinker (1965), Kolata *et al*. (1974), Kushwaha *et al*. (2011), Minar *et al*. (2013) and Jain *et al*. (2018). The highest incidence of fractures was observed in non-descript breeds (75%). This might be attributed to their free roaming habit, which made them more vulnerable to road accidents (Maala and Cleo, 1975) and a higher population. Kushwaha *et al*. (2011) and Talaat *et al*. (2022) also reported similar findings. In the present study, the incidence of proximal third diaphyseal fractures (31%) was the highest, followed by capital physeal fractures (22%), basicervical fractures (19%), subtrochanteric (10%), transcervical (9%), trochanteric avulsions (6%), and intertrochanteric fractures (3%). Similar findings have been reported by Wong (1984), De Camp *et al*. (1989), and De Camp (2016).

The most common etiological factor for proximal femur fractures in this study was automobile accidents (63%), followed by fall from height (22%), dog bite (6%), unknown etiology (6%), and forcible mating (3%). Because non-descript local dogs have the habit of roaming on free roads and highways, they are more prone to automobile accidents. In addition, automobile accidents cause high-energy trauma, which explains fractures of the proximal femur in dogs. Vehicular accidents and fall from heights were recorded as the leading causes of fracture in dogs by Singh *et al*. (1983), Whitehair and Vasseur (1992), Kushwaha *et al*. (2011), Minar *et al*. (2013), Libardoni *et al*. (2018), Jain *et al*. (2018), Kallianpur *et al*. (2018) and Soliman *et al*. (2020).

Proximal femoral fractures are not amenable to conservative management (Aparicio and Fjeld, 1993; Langley-Hobbs, 2015; Talaat *et al*., 2022) due to anatomic peculiarities of the femur (Olmstead, 1984; Brinker *et al*., 2006; De Camp *et al*., 2016; Lovric *et al*., 2020). Surgical management of femoral fractures includes intramedullary pinning, external skeletal

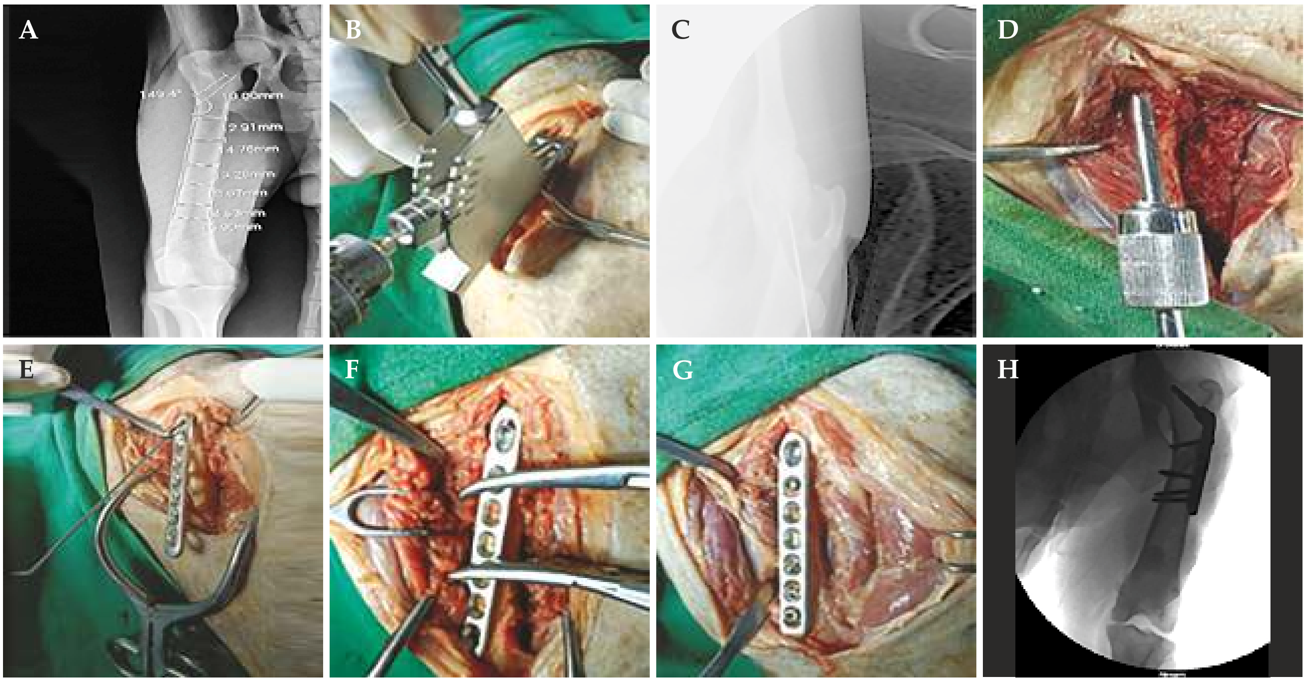

Fig. 2: Cadaver study for method standardisation: (A) Radiographic measurement of contralateral femur; (B) Insertion of guide wire into the proximal fragment from lateral surface towards the neck of the femur; (C) C-ARM image of insertion of guide wire; (D) Reaming of the barrel hole over the guide wire; (E) Fixation of the VBP to the proximal fragment and reduction of fracture; (F) Fracture fixation with VBP; (G) Final fixation of fracture with VBP; (H) Intraoperative C-ARM image after fracture fixation using VBP.

fixation, cerclage wiring, bone plating, lag screw technique, and the plate-rod technique (Braden and Brinker, 1973; Klause *et al*. 1990; Denny, 1991; Gibson and Van Ee, 1991; Lambrechts *et al*., 1993; Cabassu, 2001; Farag *et al*., 2001; Reems *et al*., 2003; Beale, 2004; Stiffler, 2004; Johnson, 2013; De Camp *et al*., 2016; Holsworth, 2018; Libardoni *et al*., 2018; Lovric *et al*., 2020; Sanchez and Perry, 2021; Wangchuk *et al*., 2021). The use of ESF is discouraged in the femur, as it has no real safe corridors (Egger, 1991; Marti and Miller, 1994; Peirone *et al*., 2002), and the intramedullary pin provides good stabilization against angular deformity (Denny, 1991). Bone plating is the technique of choice for femoral fractures; however, the paucity of bone stock in the proximal fragment is a major challenge in cases of proximal femoral fractures (Holsworth, 2018; Sanchez and Perry, 2021).

The mean implant-specific radiographic measurements in groups I, II and III are presented in table 1. The range of implant-specific femoral neck-shaft angles in group I (n=72) was 131.35°-152°, in group II (n=142) was 131.09°-157.20° and in group III (n=56) was 134.30°-152.10°. To design a novel Veterinary Barrel Plate and screw, the average measurement of group II (medium-sized) was chosen as the standard because of the higher population of medium-sized dogs in the region and ease of manufacturing. The neck-shaft angle was standardized to 140° and 150°, as the site of fracture included in the study was at any point between the neck and the proximal third of the femoral shaft, and the barrel of the novel Veterinary Barrel Plate was placed above the fracture site.

In the present study, a cadaver study was performed to standardize the veterinary barrel-plating technique. The crucial step was the proper insertion of the guide wire into the neck of the femur at a predetermined angle (determined from the preoperative craniocaudal radiographic view) using the variable angle guide under C-arm imaging (Fig. 2C). The necessity of intraoperative imaging for accurate implant placement was also reported by Johnson *et al*. (1998), Badjate and Cariappa (2005), Schmokel *et al*. (2007), Haaland *et al*. (2009) and Jones *et al*. (2015). In veterinary barrel plating, the VBP is first fixed to the proximal fragment, followed by reduction of the fracture and fixation of the distal fragment, whereas in the standard straight plating technique, fracture reduction is followed by plate fixation (De Camp *et al*., 2016). The fixation of the implant to the shorter proximal fragment facilitated easier manoeuvring of the fragments during fracture reduction.

In the present study, screw pull-out strength, three-point bending, and axial compression tests were performed. It was observed that the mean screw pullout strength of the barrel screw was 740.77 N and that of the bicortical plate screws was 605 N, which implied that the screw pullout strength of the proximal femur was greater than that of the femoral diaphysis. For a locking construct to fail, the thread purchases of all screws must be overcome (Tejwani and Guerado, 2011). Screws placed in a mediolateral plane are significantly stronger than screws applied in a craniocaudal plane (Gautier and Sommer, 2003; Voss *et al*., 2009 and Gordon *et al*., 2010). In the present study, the screws were placed in the mediolateral plane, which contributed to the maximum strength of the construct.

During the three-point bending test, it was observed that the ultimate bending load for deformation of the plate-bone construct (626 N) and the VBP alone (448 N) was less than that of the intact femur (688 N). The higher bending load of the intact femur could be due to the material property of the intact bone, and the complex stress distribution in the cancellous bone (Radasch, 1999; Gardner *et al*., 2005; Shahar *et al*., 2003). Lotz *et al*. (1991) found that maximum load bearing was observed in the subcapital, intertrochanteric and subtrochanteric regions of the femur. Sanchez and Perry (2021) reported that fracture of the bone occurred when loading forces increased beyond the threshold of the elastic modulus of the bone. Schwarz (1991) observed that bone plates provide the most stable form of fracture fixation and are effective in neutralizing compression, tension, shear, torsion, and rotation forces at the fracture site. Dickson and Munz (2007) reported that locked plates had different biomechanics in axial loading, bending and torsion and locked plates created an additional cortex and distributed the deforming loads to all the screws equally. In the present study, the results showed that the bending strength of the bone-plate construct was lower than that of the intact bone, thus preventing stress shielding. It was inferred that stress shielding would not be caused, and a minimum amount of load, which is a pre-condition for fracture healing (Yamada, 1970), would be present *in vivo*. The ultimate bending load of the VBP alone was less than that of the bone-plate construct, which could be explained by the fact that locking plates and locking head screws created a single beam construct, which was stronger than the plate alone, and locking plates converted shear stress to compressive stress at the screw-bone interface to which the bone had much higher resistance. This is in accordance with the opinions of Aguila *et al*. (2005) and Tejwani and Guerado (2011).

In the present study, the average axial compression load of the VBP was recorded to be 1082.81 N, which implied that the chances of plate bending at physiological loads were minimal. As the implant was designed for the first time, there are no studies or data available for comparison.

From the present study, it can be concluded that the determination of radiographic measurements of femoral neck angles, including implant- and fracture-specific parameters, aided in the design and development of suitable angle-stable Veterinary Barrel Plates and barrel screws as an addition to the armamentarium of veterinary orthopaedics for the effective fixation of proximal one-third femoral fractures in dogs. The inclusion of fracture level as an additional criterion for measuring the neck-shaft angle, which had not been considered in previous studies, may further aid in the development of customised angle-stable implants and improved techniques for stabilisation of proximal femoral fractures. Insertion of the guide wire into the femoral neck under C-arm guidance was identified as the most critical step for achieving accurate implant placement and adequate fracture fixation using the barrel plating technique.

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