

MEASUREMENT OF THE FEMORAL NECK ANGLE IN MEDIUM AND LARGE DOG BREEDS USING COMPUTED TOMOGRAPHY

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The aim of this study was to get precise normal values of the femoral neck angle (FNA) in support of developing an optimally functioning total hip prosthesis for medium and large dog breeds. Accordingly, two- and three-dimensional computed tomographic images of the anatomical structures of the proximal femora of 58, hip-dysplasia-free, mature dogs of medium and large breeds were studied. Based on the length of their femora the dogs were allocated to Group I (from 145 to 195 mm) and Group II (from 196 to 240 mm). The FNA was measured on each femur using multi-slice spiral computed tomography (CT). The two- and three-dimensional image data were processed as multi-planar and three-dimensional reconstructions using Advantage Workstation software. The CT measurements revealed that Group I had an average femoral neck angle of 147.59° (min. 144.05°, max. 153.35°), while in Group II the average FNA was 147.46° (min. 141°, max. 154.35°). There was no significant correlation between the length of the femur and the FNA in either group. The optimal FNA for a total hip prosthesis is 147.5° for medium and large dog breeds.

Key words: Canine, total hip replacement, femoral morphology, femoral neck angle, total hip prosthesis

In the clinical assessment of hip joint health, the femoral neck angle (FNA) is a highly significant and frequently used measure (Adams et al., 2017). Here the FNA is defined as the angle formed by the intersection of the longitudinal axis of the femoral shaft and that of the femoral neck (Hauptman et al., 1979) (Fig. 1). In adult medium to large dog breeds with normal hip joint morphology the FNA has been reported to be within the range of 129.11° to 153.8° degree

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(Hauptman et al., 1979; Hauptman et al., 1985; Sumner et al., 1990; Martins et al., 2012; Lusetti et al., 2017). However, there are many relatively common congenital and developmental conditions where the FNA deviates significantly from the normal such as coxa valga where the FNA is above the normal, and coxa vara where the FNA is lower than normal (Adams et al., 2017).

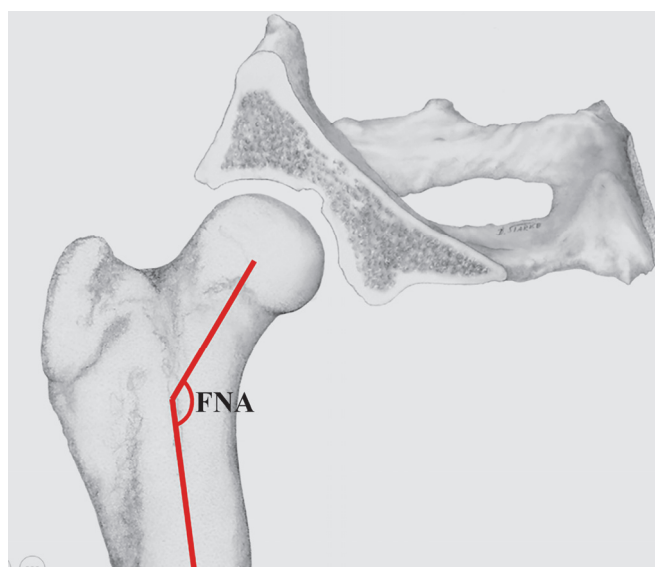


Fig. 1. An illustration of the normal position of the femoral head within the acetabulum in a dog with a normal femoral neck angle (FNA)

Surgical correction of serious hip problems frequently requires total hip replacement (Dudley et al., 2006; Bausman and Wendelburg, 2013). For these, a detailed knowledge of the morphology of the dog's proximal femur is required for the development of an ideal hip joint prosthesis (Noble et al., 1988; Sumner et al., 1990; Palierne et al., 2006). The accurate colocation of the femoral head with the acetabulum is critical in healthy dogs; hence, the correct angulation of the femoral head and neck is an important factor in the development of total hip prostheses (Sumner et al., 1990; Palierne et al., 2006). Accurate measurements of the FNA are important for understanding the geometric configuration of the bony joint structures and the biomechanics of the hip joint, so that the design of total hip prosthesis can be optimised (Hauptman et al., 1985; Sumner et al., 1990; Palierne et al., 2006).

Historically the FNA has been measured using a variety of techniques including routine radiography (Montavon et al., 1985; Sumner et al., 1990; Sarierler, 2004; Palierne et al., 2006), and more recently two-dimensional (2D) (Ocal et al., 2004; Bäcker, 2010; Lusetti et al., 2017) and three-dimensional (3D) recon-

structed computed tomography (CT) (Hartel et al., 2016; Savio et al., 2016). Measurement of the FNA using routine classical radiographic methods can be technically challenging and time consuming as well as being subject to operator experience and biases (Dudley et al., 2006; Jackson and Wendelburg, 2012). Establishing the femoral axis is the starting point for the cascade of measures to ultimately determine the FNA (Tomlinson et al., 2007). However, these measurement points are poorly defined in X-ray images due to superimposition-related errors when compared to those of CT images (Bäcker, 2010).

The greater clarity of structural images using CT allows a precise determination of the medullary axis of the femur; this in turn allows more accurate determination of the subset of femoral head and neck measurements that are needed for the development of total hip prostheses (Bäcker, 2010; Savio et al., 2016). We used CT to get precise normal values of the FNA in medium and large dog breeds in order to develop an optimally functioning total hip prosthesis for these dog breeds.

Materials and methods

Computed tomographic studies were conducted on the proximal femora of 58 mature dogs, all free of hip dysplasia, that had died or were euthanised for medical reasons at the Small Animal Clinic, Free University of Berlin in accordance with the research ethics code of the institution and with the written permission of the animal owner. Each dog was weighed to an accuracy of 0.01 kg on a digital scale (Animal Platform Scale, HITSAN). Dogs were assigned into two groups based on the length of their femur (Palierne et al., 2008). Group I had 25 dogs, whose femoral length was between 145 and 195 mm, while Group II included 33 dogs with a femoral length between 196 and 240 mm.

The German Shepherd was the most frequent breed with an almost balanced sex ratio, followed by Labradors and Golden Retrievers. Other breeds, such as Staffordshire Terriers, Boxers, Rottweilers, Bullmastiffs and Weimaraners, were less frequent in this study. The dogs used in this study included 17 castrated females, 4 intact females, 2 castrated males and 35 intact males.

To ensure that the animals used in this study were normal and free of any orthopaedic disease, we performed the Ortolani and Barlow test on the live dogs before their euthanasia, while radiographic and computer tomographic evaluations of the hip joint were conducted on all studied dogs after their euthanasia. None of the dogs studied had a clinical history of hindlimb lameness as reported by the owners, moreover all hip joints that had radiographic signs of hip joint dysplasia on CT examination were excluded. The FNA was measured using two- and three-dimensional CT at the Small Animal Clinic, Free University of Berlin. The CT used multi-slice spiral computed tomography 'Lightspeed' QXi (General Electric Healthcare, GE). The slice thickness selected was (0.3 mm), the kilovoltage setting was 120 kV and the milliamperere-seconds (mAs) setting was 130 mAs.

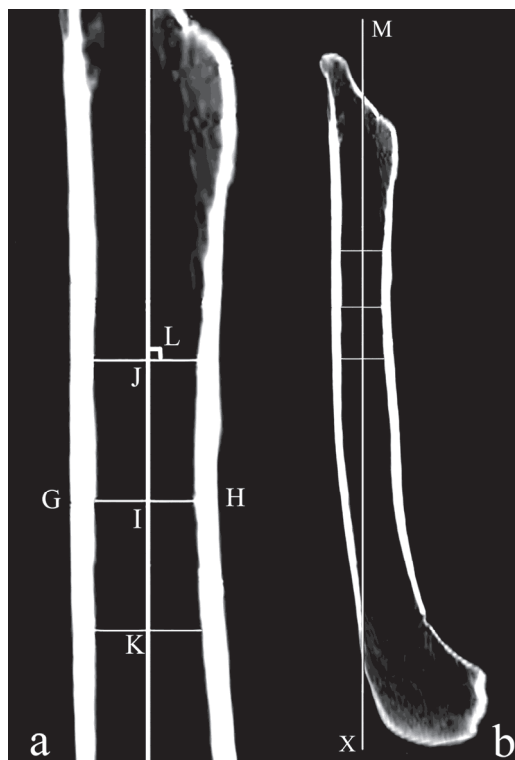


Fig. 2. Sagittal plane view of the femur where (a) is a high resolution of the proximal region and (b) is an image of the complete femur. Here GH is the intracortical width at the narrowest point of the femoral shaft and I is its centre point. J and K are central points 2 cm proximal and 2 cm distal to I, respectively. MX is the medullary axis. L is the right angle between the medullary axis and the width (GH)

The dogs were positioned on their back on the CT scanner's table and, to avoid rotation of the femoral bones, the hindlimbs were fixed with adhesive strips (Tesa AG Hamburg) at the level of the tarsal joint.

The images were analysed using a workstation (Advantage Workstation 4.2; GE Healthcare). The data record was processed as multi-planar and three-dimensional reconstructions using the same Advantage Workstation software.

The sequence of femoral measurements to determine the axis of the femoral shaft, length of the femur, centre of the femoral head, axis of the femoral neck and the femoral neck angle were always performed in the same order as some measurements were reliant on values of earlier measurements. To ensure precision, all measurements were performed twice at a time interval of one day, and then the mean values determined.

The data were analysed statistically by using Statistical Packages for Social Sciences software (SPSS Inc. Version 20, Chicago IL, USA).

Medullary axis of the femoral shaft

To ensure accurate comparability in femoral measurements sagittal plane views were all made with the caudal aspects of both femoral condyles at the same level and the femoral axis positioned vertically to avoid any cranial or caudal inclination of the femur (Fig. 2). From here the femora were rotated 90° cranially to ensure an accurate frontal plane view and to avoid any external or internal rotation of the femur.

In the frontal plane view, the centre (C) of the intracortical width (AB) was established at the narrowest point of the femoral shaft. Using the same methodology an additional central point (D) was determined 2 cm proximal to C and a third central point (E) was determined 2 cm distal to C (Fig. 3).

The axis of the femoral shaft was defined as the line connecting the points C, D and E that forms a right angle to width AB (Fig. 3).

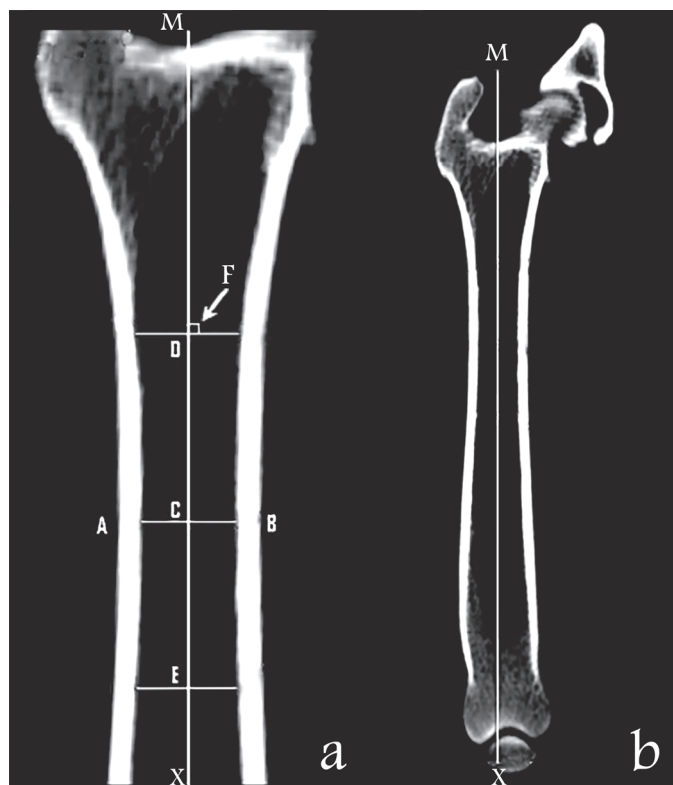


Fig. 3. Frontal plane view of the femur where (a) is a high resolution of the proximal region and (b) is an image of the complete femur. Here AB is the intracortical width at the narrowest point of the femoral shaft and C is its centre point. D and E are central points 2 cm proximal and 2 cm distal to C, respectively. MX is the medullary axis. F is the right angle between the medullary axis and the width (AB)

Length of the femur

Using a three-dimensional rendering of the femur in frontal plane view, the length of the femur was determined to be the line immediately parallel to the femoral axis that connects the orthogonal lines at the most proximal point of the femoral head and at the most distal end of the femoral condyles (Fig. 4). The length of the femur was used to allocate the dogs into Group I (from 145 to 195 mm) and Group II (from 196 to 240 mm).

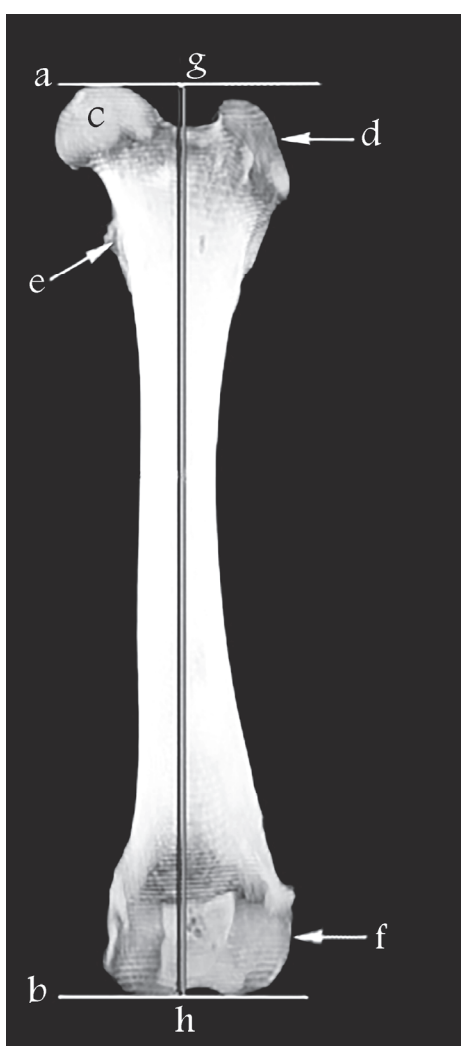


Fig. 4. Frontal plane view of the femur: (a) proximal orthogonal, (b) distal orthogonal, (c) femoral head, (d) great trochanter, (e) lesser trochanter, (f) lateral condyle, (gh) length of the femur connecting the proximal orthogonal at (g) to the distal orthogonal at (h)

Centre of the femoral head

Using a 3D rendering of the femur in frontal plane view, the centre of the femoral head was identified by using annotation software to generate concentric circles of best fit and superimpose these onto the femoral head. The circle of best fit was identified and its centre marked the centre of the femoral head (Fig. 5).

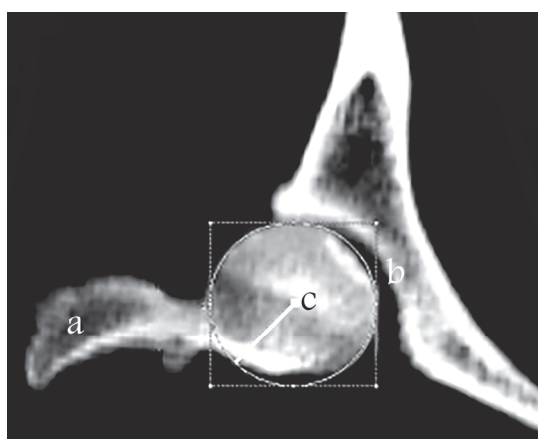


Fig. 5. Frontal plane view of the proximal femur: (a) great trochanter, (b) acetabular cavity, (c) centre of the femoral head

Axis of the femoral neck

The axis of the femoral neck was defined as the line passing from the centre of the femoral head to form a right angle at the midpoint of the base of the femoral neck. This is on the line between the deepest point of the trochanteric fossa and the medial cortex of the femur at the level of the lesser trochanter (Fig. 6). Here the centre of the femoral head and the midpoint of the base of the femoral neck are located in two different frontal plane slices due to the cranial femoral head and neck antetorsion to the femoral shaft. This explains the difference in shape of the femoral head in Figs 5 and 6.

Femoral neck angle

The FNA is the angle between the axis of the femoral neck and the medullary axis of the femoral shaft (Fig. 7).

Results

In this study, 116 femora in 58, hip-dysplasia-free, mature dogs of medium and large breeds were measured.

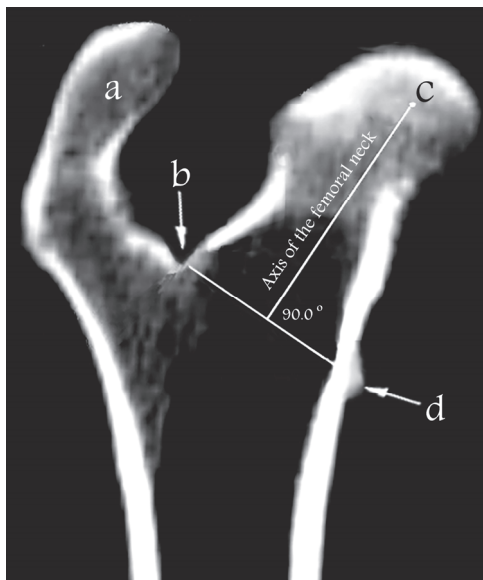


Fig. 6. Frontal plane view of the femur: (a) great trochanter, (b) deepest point of the trochanteric fossa, (c) centre of the femoral head, (d) lesser trochanter. The axis of the femoral neck is the line drawn from the centre of the femoral head to be orthogonal to the line joining (b) and (d)

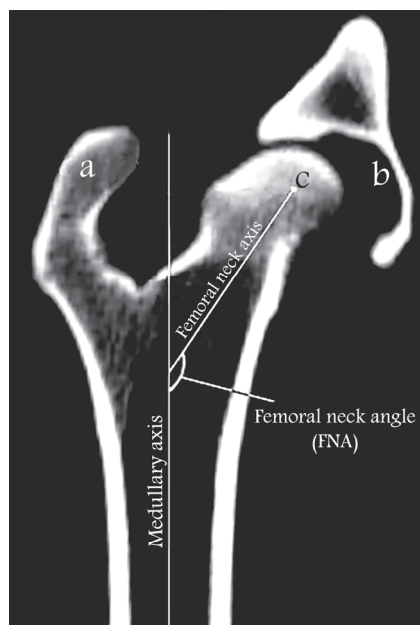


Fig. 7. Frontal plane view of the femur: (a) great trochanter, (b) acetabular cavity, (c) centre of the femoral head. The femoral neck angle (FNA) lies between the femoral neck axis and the medullary axis of the femur

In Group I, the average age of the dogs was 7.6 years with a minimum of 2 years and a maximum of 16 years, while the average body weight was 27.8 kg with a minimum of 17 kg and a maximum of 45 kg. The average age of the dogs in Group II was 8.4 years with a minimum of 1.5 years and a maximum of 16 years, while the average body weight was 42.3 kg with a minimum of 22 kg and a maximum of 60 kg.

Femoral neck angle (FNA)

In the present study, the mean FNA values were 147.59° (SD ± 2.24 , range 144.05° – 153.35°) for Group I and 147.46° (SD ± 3.05 , range 141° – 154.35°) for Group II. The comparison of the measured values of the FNA in box plot (Fig. 8) revealed no significant difference between Groups I and II, and no correlation between the length of the femur and the femoral neck angle.

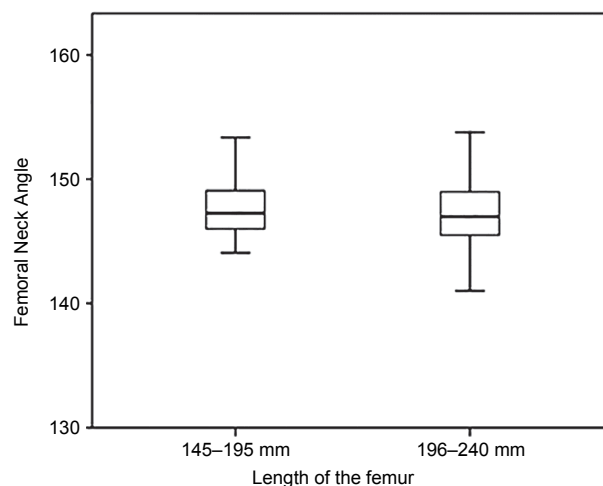


Fig. 8. Femoral neck angle (FNA) and length of the femur in Groups I and II. Results are presented as a boxplot with medians and data ranges

Discussion

Since the first hip prosthetic implant in a dog with hip dysplasia in 1974 (Olmstead et al., 1983), total hip arthroplasty in veterinary medicine has been evolving continuously (Guerrero and Montavon, 2009). The design and modularisation of hip prostheses as well as the techniques of implantation have been the subject of many studies (Sumner et al., 1990; Bloebaum et al., 1993; Paliarne et al., 2006; Bausman and Wendelburg, 2013). Complications following hip joint replacement include aseptic loosening, implant subsidence, infection, and im-

plant-associated fracture; however, hip luxation was and continues to be the most frequently reported complication for both cemented and uncemented hip prostheses (Bergh et al., 2006; Nelson et al., 2007; Guerrero and Montavon, 2009; Bausman and Wendelburg, 2013). Consequently, detailed knowledge of the normal values of the geometric parameters of the femur support the recognition, understanding and treatment of pathologic conditions of the hip joint. This in turn allows the development of optimally functioning hip joint prostheses that closely mimic the hip joint architecture, thus playing an important role in achieving favourable functional outcomes (Tonnis and Heinecke, 1999; Hartel et al., 2016). This knowledge improves long-term success rates and reduces postoperative complication rates such as cortical bone loss, fractures and prosthesis luxation by ensuring optimal positioning of the hip prosthesis (Guerrero and Montavon, 2009). Like Paliarne et al. (2008) who studied a large number of dogs of quite different body sizes we did not include the body mass of the dogs as a morphological parameter due to the variability in their history and nutritional status. In their study of femoral characters such as the size of the femoral head, FNA, and the length of the femoral neck they found that the total length of the femur was the most reliable parameter to divide the dog population into similar functional size groups (Paliarne et al., 2008).

The FNA is described as one of the most important parameters of the proximal end of the femur in the development of hip dysplasia (Prieur, 1980; Adams et al., 2017). Some studies have reported that there is no difference in the FNA of dysplastic and non-dysplastic dogs (Hauptman et al., 1985; Sarserler, 2004). Contrary to this, however, other studies report that there is a greater FNA in dogs with hip dysplasia (Prieur, 1980; Montavon et al., 1985; Bloebaum et al., 1993). Most studies measured the FNA for medium and large dog breeds using standard radiographic methods and reported the FNA as follows: Sterchi (1980) 147°, Schawalder and Sterchi (1981) 142°, Hauptman et al. (1985) 143°, Montavon et al. (1985) 144.7°, Sumner et al. (1990) 147.4°. Paliarne et al. (2006), who included small, medium and large dog breeds in their study, reported that the average FNA was 140.9°. This lower measure is most probably due to the inclusion of small dogs that have a smaller FNA. This was confirmed by Bäcker (2010) who measured the FNA of small dog breeds using CT and reported an FNA with a mean value of 138.2°.

The Prosthesis Inclination Angle (PIA) is the prosthetic equivalent of the FNA in live dogs and is determined by each implant manufacturer's design. For BioMedtrix (CFXTM cemented fixation and BFXTM biologic fixation systems) it is 135° and for the Kyon uncemented system it is 145° (Bausman and Wendelburg, 2013). This angle should match the normal values of the FNA (Bausman and Wendelburg, 2013).

Accurate determination of the femoral neck axis is crucial to the measurement and determination of the FNA (Tomlinson et al., 2007). Any rotation of

the femur either internally or externally from the true frontal plane, and any error in the sagittal plane position of the femur alters the measurement of the inclination angle in dogs (Beck et al., 1992; Miles, 2016). Elevation of the femur from being horizontal to the X-ray beam also affects the measurement of the anatomical lateral distal femoral angle (Miles et al., 2015). In this study strict adherence to the accepted methodologies nullified any possible sagittal inclination, external or internal rotation of the femur and antetorsion of the femoral neck.

In the present study the mean value of the FNA was 147.59° in dogs with a femur length between 145 and 195 mm (Group I) and it was 147.46° in dogs with a femur length between 196 and 240 mm (Group II). These results are comparable to those of Sterchi (1980) with an FNA of 147° , Montavon et al. (1985) at 144.7° and Sumner et al. (1990) at 147.4° . The FNA measured in this study shows no significant difference between Group I and Group II. Likewise, there was no correlation between the length of the femur and the FNA (Fig. 8). According to this study, any new hip joint prosthesis should have an FNA of 147.5° for both medium and large dog breeds. We emphasise the importance of the FNA, which is critical in the development of properly designed, highly functional total hip prostheses. This will, in turn, improve the long-term success rate and reduce the postoperative complications associated with hip joint replacement.

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