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Araştırma Makalesi **Research Article**

The Geometry of the Proximal Femoral Medullary Canal in German Shepherd and Kangal Dogs[#]

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Abstract

The proximal femur has morphological variability that is related to its functional and biomechanical properties. Therefore, researchers have long been interested in these variations especially associated with the femoral implant design and implantation in total hip arthroplasty. The positions of the femoral head and the geometrical variations in the medullary canal are evaluated in particular to understand the proximal femoral morphology. The position of head or neck of the dog has already been studied in detail. There are incomplete data to evaluate variations in the geometry of the medullary canal of proximal femur in dog. Proximal femoral morphology of the medullary canal has been evaluated only at the coronal plane in dog studies using plain radiography. The morphometric data on the sagittal plane are also need to innovations in femoral implants. The purpose of this study is to indicate the detailed geometric data about proximal femoral canal of dog using three-dimensional morphometric methods to provide a database for the orthopedic studies. The effect of the breed with different pelvic limb conformation was also studied in this study. The cleaned femora from 16 German shepherd and 16 Kangal dogs were used. The three-dimensional images were reconstructed from the computed tomographic images. The femoral length, the anteversion angle and neck angles, the isthmus position and the widths on medio-lateral and cranio-caudal directions of the cross-sections of proximal femur were measured. The cortico-medullary indices, the isthmus position index and the canal flare indices were also calculated to detailed investigation of medullary canal of the proximal femur. According to our study results, it must be considered in stem design that the level of the isthmus might change in response to different conformations of the dog breeds, whilst the flare indices are similar in the dogs. The flare of the medullary canal was firstly evaluated with the cranio-caudal diameters on the three-dimensional images in this study. The cortico-medullary index shows some variation between the dog breeds across the levels and the directions of the cross-sections of the proximal femur. Nowadays, three-dimensional images can be acquired and morphometric measurements can be done easily by tomography in a lot of veterinary clinics. The data from three-dimensional morphometric analysis may contribute to the optimization of the design and preoperative selection of femoral implants by surgeons.

Özet

Kangal ve Alman Çoban Köpeklerinin Proximal Femur Bölümünde Cavum Medullare'nin Geometrik Özellikleri

Proximal femur, fonksiyonel ve biyomekanik özellikleri nedeniyle morfolojik varyasyonlar gösterebilir. Bu varyasyonlar, total kalça protezinin femoral implant uygulamaları ve tasarım çalışmalarında araştırıcılar için önemlidir. Proximal femur'un morfolojik özelliklerine ilişkin olarak, caput femoris pozisyonu ve cavum medullare'nin geometrik varyasyonları öncelikli olarak incelenir. Köpeklerde caput femoris pozisyonuna ilişkin çalışmalar daha çok görülmekle birlikte cavum medullare'nin geometrik özelliklerine ilişkin çalışmalar yetersizdir. Ayrıca bu bölgeye ilişkin morfometrik ölçümler sadece dorsal (coronal) düzlemde yapılmıştır. Yeni femoral implant tasarımları için yapılacak çalışmalar için bölgenin sagittal düzlemde de elde edilmiş morfometrik verilerine ihtiyaç

[#]This study is a part of the unpublished PhD thesis of the corresponding author.

vardır. Bu çalışmada da ortopedik çalışmalar için veri tabanına katkıda bulunmak amacıyla proximal femoral kanalın, bilgisayar ortamında üç boyutlu modelleri kullanılarak detaylı geometrik ve morfometrik verilerin sunulması amaçlanmıştır. Ayrıca, farklı arka bacak konformasyonlardaki iki ırktan elde edilen veriler de karşılaştırılmıştır. Çalışmada 16 adet Kangal ve 16 adet Alman çoban köpeğine ait femur'lar kullanıldı. Bilgisayarlı tomografi kesitleri kullanılarak kemiklerin üç boyutlu modelleri hazırlandı. Bu modellerden femur uzunluğu, anteversiyon açısı, collum femoris açısı, isthmus pozisyonu ve proximal femur bölgesinden alınan kesitlerde medio-lateral ve cranio-caudal çaplar ölçüldü. Ayrıca proximal femoral kanalın detaylı incelenmesi için kesitlerin cortico-medullar oranlar, isthmus pozisyonu oranı ve medullar kanal genişleme oranları hesaplandı. Çalışma sonuçlarına göre medullar kanal genişleme oranları benzerlik gösterse de isthmus mesafesinin köpek ırkları arasında farklılık gösterebileceği dikkati çekti. Köpeklerde, proximal medullar kanalın yukarı doğru açılmasına ilişkin cranio-caudal yönlü hesaplanan oran ilk defa değerlendirilmiştir. Cortico–medullar oranlar bazı seviyelerde veya yönlerde iki ırk arasında farklılık göstermiştir. Günümüzde bir çok klinikte bulunan tomografi cihazları ile kemiklerin üç boyutlu modelleri rahatlıkla elde edilebilir ve morfometrik değerlendirmeler yapılabilir. Bu çalışmada elde edilen morfometrik verilerin, klinisyenlerin uygun femoral implant seçiminde ve yeni tasarımların yapılabilmesinde yardımcı olabileceği düşünülmektedir.

Introduction

The proximal part of the femur has morphological variability that is related to its functional and biomechanical properties. The anatomists and orthopedic surgeons have long been interested in the variations of proximal femoral morphology especially associated with the femoral implant design and implantation in total hip arthroplasty (THA) (Abadie et al., 2010; Husmann et al., 1997; Noble et al., 1988; Palierne et al., 2008; Rawal et al., 2012; Tawada et al., 2015). Although different types of the implants are available from the manufacturers, the database for size and shape characteristics of proximal femur has still required to designing new implant and auxiliary equipment and to enhance the performance or longevity of the implants (Casper et al., 2012; Chantarapanich et al., 2011; Ganz et al., 2010; Laine et al., 2000; Noble et al., 2003; Peck et al., 2013; Rashmir-Raven and DeYoung, 1992; Umer et al., 2010; Yang et al., 2014). Understanding the variations of the proximal femur may also guide surgeons in proper implant selection to decrease postoperative complications. Because, the close adaptation of the prosthesis to the bone is essential to achieving optimal mechanical stability and fixation for THA (Casper et al., 2012; Ganz et al., 2010; Peck et al., 2013; Umer et al., 2010; Yang et al., 2014)

The morphometric method to understand the shape and size of the proximal femur regarding femoral stem design was firstly described in detail by Noble et al. (1988) in human femur. In this method, to understand the proximal femoral morphology with relevance for THA, the position of the femoral head and the geometrical variations in the medullary canal should be evaluated in particular (Franklin et al., 2012; Husmann et al., 1997; Noble et al., 1988; Noble et al., 2003; Palierne et al., 2008; Tawada et al., 2015; Yang et al., 2014). The position of femoral head or neck of the dog has already been studied in detail (Dudley et al., 2006; Franklin et al., 2012; Kuo et al., 1998; Madsen and Svalostaga, 1994; Palierne et al., 2006; Palierne et al., 2008; Rumph and Hathcock, 1990; Sarierler, 2004; Tomlinson et al., 2007; Wigger et al., 2008). To the best of our knowledge there are incomplete data to evaluate variations in the geometry of the medullary canal of proximal femur in dog. The isthmus position index (IPI), the cortico-medullary index (CMI) and the canal flare index (CFI) are the most useful bone indices to evaluate objectively proximal femoral geometry in respect to THA (Abadie et al., 2010; Breusch, 2005; Noble et al., 1988; Noble et al., 2003; Palierne et al., 2006; Palierne et al., 2008; Rawal et al., 2012; Umer et al., 2010; Yeung et al., 2006; Yang et al., 2014). The isthmus position is measured in human femur studies (Noble et al., 1998; Noble et al., 2003; Rawal et al., 2012; Sugano et al., 1998; Umer et al., 2010; Yang et al., 2014). For dogs, the proximal and distal borders of isthmus are described with the IPI by Palierne et al. 2006 and Palierne et al. 2008. Although, the CMI of dog femur has been indicated on the mid-regions and in the coronal plane (Palierne et al., 2008), the cross-sectional data throughout the proximal femur in both direction may more useful to best understanding of proximal femur (Noble et al., 2003; Rawal et al., 2012; Sen et al., 2010; Yang et al., 2014). The proximally flare of the medullary canal of femur is described as the canal flare index which is the most used parameter in the THA studies (Noble et al., 1988; Noble et al., 2003; Tawada et al., 2015). But, there is some controversial data about the CFI values on dog femur (Ganz et al., 2010; Marcellin-Little et al., 1999; Palierne et al., 2006-2008; Pugliese, 2014; Rashmir-Raven and DeYoung, 1992).

Proximal femoral morphology of the medullary canal has been evaluated only at the coronal plane in dog studies using plain radiography (Ganz et al., 2010; Marcellin-Little et al., 1999; Marsolais et al., 2009; Palierne et al., 2006; Palierne et al., 2008; Pugliese, 2014; Rashmir-Raven and DeYoung, 1992). The morpho-metric data on the sagittal plane are also need to innovations in some kind of the cementless implants, especially (Laine et al., 2000; Noble et al., 2003; Rawal et al., 2012; Sen et al., 2010).

The progress of some engineering technologies such as CT scanner and reverse engineering enables the construction of three-dimensional medical models. This allows examining the complex geometry which may be difficult to carry out based on conventional two-dimensional radiographic technique (Chantarapanich et al., 2011) Therefore, in human medical literature, three-dimensional measurement methods have been widely used for reliable measuring of head-neck position and medullary canal shape of femur regarding new designs of hip implants. (Husmann et al., 1997; Noble et al., 2003; Sugano et al., 1998; Tawada et al., 2015).

There have been some studies about race variances in human proximal femoral canal (Rawal et al., 2012; Tawada et al., 2015; Umer et al., 2010; Yang et al., 2014; Yeung et al., 2006), however, there is no adequate studies about it in dog breeds. Because of the great number of dog breeds the studies about breed-specific comparison may not possible for each breed (Palierne et al., 2008). It is well known that the shapes of bones are affected by the direction and magnitude of the mechanical force (Amman and Rizzoli, 2003) The hind limb conformation varies greatly among the dog breeds (Dyce et al., 2002; Evans, 1993) and the mechanical forces can vary in different conformations (Voss et al., 2011). The locomotion of dog may also be influenced by the differences in breed and conformation (Voss et al., 2011). Sabanci (2015) determined the hind limb posture objectively by using the angles and percentages of the height measurements of hind limb in different breeds of dogs. According to this study German shepherds (GSD) have the most angulated pelvic limbs while the others of some breeds such as Kangal Dog (KD) have more straight pelvic limbs.

The purpose of this study is to indicate the detailed geometric data about proximal femoral canal of dog using three-dimensional morphometric methods to provide a database for the THA studies. The effect of the breed with different pelvic limb conformation was also studied in this study.

Materials and Methods

Sixty four cleaned femur from 16 German shepherd (GSD) and 16 Kangal dogs (KD) were used in this study. The bones have no gross pathological changes and they were from skeletally mature dogs. This research was approved by the ethics committee of the Adnan Menderes University under number 2008/037.

The three-dimensional (3D) images were reconstructed from CT images. For this purpose, the entire femora were scanned at 1 mm thickness and 1 mm intervals by TOSHIBA-Aquilion 64 CT (120 KV, 125 mAs) and the images were saved as DICOM (Digital Imaging and Communications in Medicine) files. These images were processed using 3D-Doctor Software (Able, USA) to obtain a 3D reconstruction of the internal and external geometries of each femur. Semi-automatic segmentation was done by determining the cortical bone boundaries. The incorrect bone boundaries were reedited using a pen tablet (Intuos4, Wacom comp., USA). The digital radiographic images of the bones were also used to confirm boundary marking. All the edited boundaries of the bone surfaces were stacked and overlaid to reconstruct the 3D model of bones by 3D Doctor Software. The position of bones and measurement points were defined. The rendered point cloud computer models saved OBJ format on 3D-Doctor and then transferred to the Solid Works software. These files were converted into solid bodies and were saved as ".iges" (Initial Graphics Exchange Specification) files. After the reference planes were defined, the models were neutrally aligned in space with respect to a global "xyz" orthogonal frame of reference according to Kim et al. (2000).

The morphometric measurements were done with Solid Works software. The morphometric landmarks and measurements were adapted from Noble et al. 2003, Palierne et al. 2006, and Palierne et al. 2008. The center of the femoral head was defined as the center of the best fitted sphere of the head. The medullary axis of the femur was defined by a line passing through the centers of the medullary canal at the proximal quarter and at the middle of the bone. Neck axis was defined between the center of the head and center of the neck. The isthmus was defined as the smallest medullary diameter level of the shaft both on the medio-lateral view. The lesser trochanter point was defined as most medial point of the lesser trochanter. The mid-shaft was defined as midpoint of the femoral length.

After defining the landmarks the following parameters were generated for each femur. The femoral length was measured between the most proximal point of bone and the distal edges of the condyles. The Anteversion angle was measured between neck axis and the tangential line of the caudal tip points of femoral condyles. Neck-shaft angle was measured between neck axis and medullary axis at coronal (dorsal) plane. The intracortical and extracortical widths on medio-lateral and cranio-caudal directions of cross-sections were measured. These measurements were generated at the five levels of proximal femur as the mid-shaft, the isthmus, the lesser trochanter point, and the proximal and distal borders of the lesser trochanter. The isthmus position was defined as distance from the top of the femur to level of the isthmus parallel to the medullary axis.

The indices were also calculated to detailed investigation of medullary canal of the proximal femur. The cortico-medullary indices were the ratio of the intracortical widths to extracortical widths at the five cross-sections. The isthmus position index was the ratio of femoral isthmus distance to the femoral length, expressed as a percentage by bone length. The metaphysial canal flare indices were the ratio of intracortical widths at the proximal extremity to at the distal extremity of lesser trochanter. The canal flare index (CFI) was the ratio of the intracortical width at the proximal level of lesser trochanter point and at the isthmus (Palierne et al., 2006-2008). The cortico-medullary indices and the canal flare index were also calculated both on the cranio-caudal and medio-lateral directions. The measurements are illustrated in Figure 1.

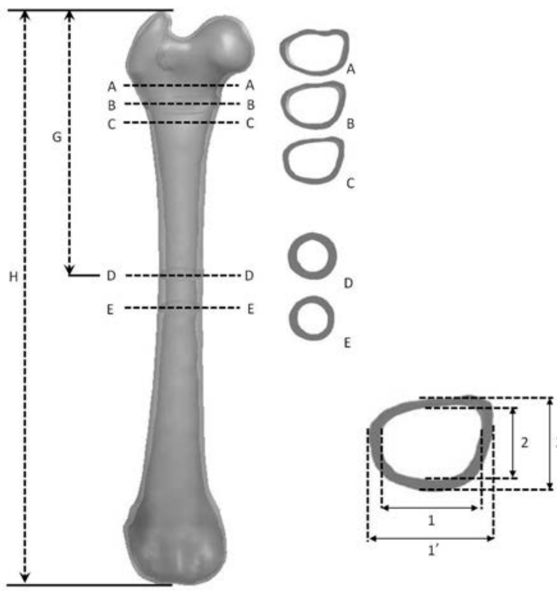

Figure 1. The cross-sections at the proximal border of lesser trochanter (A), at the level of lesser trochanter (B), at the distal border of lesser trochanter (C), at the level of isthmus (D), at the level of midshaft (E). The medio-lateral (1) and cranio-caudal (2) widths on the cross-sections. Isthmus distance (G), Femoral length (H).

Şekil 1. Trochanter minor'un proximal (A), orta (B) ve distal (C) bölgesi, isthmus seviyesi (D), kemiğin ortasından (E) alınan kesitler. Kesit görüntülerde medio-lateral (1) ve cranio-caudal) yönlü çap ölçümleri. İsthmus mesafesi (G), Femur uzunluğu (H).

The same investigator (FSK) completed all measurements in an attempt to eliminate any possibility of inter observer variability concerns. For assessment of repeatability of the measurements, five images were prepared from a femur and each was measured independently. The coefficients of variation were then calculated for each measurement as (standard deviation/mean) X 100 (Ozdamar, 2015; Palierne et al., 2008).

The statistical analyses were performed using a statistical package program (SPSS 19.0 for Windows). Right and left femurs were compared using the paired t-test. There were no statistical differences between the right and left femora, the averaged data of right and left sides were used in statistical analyses. The mean values, standard deviations were calculated for each parameter: The 95% confidence intervals were also calculated for index data. The Student's t-test was used to compare the measurements from GSD and KD. The Mann-Whitney U-test was also used for non-parametric distributions of data.

Results

The values of coefficients of variation ranged from 0.56% for the neck-shaft angle to 4.94% for the medio-lateral intracortical width at the isthmus.

The body weights of used animals were 28.81±7.33 and 41.75±9.90 kg. for GSD and KD, respectively. There was also statistically difference between two breeds of weights ($p<0.000$).

The direct measurements of the used femora are presented in Table 1. KD has significantly longer femora than GSD. The neck-shaft angle on KD was slightly higher (about 4%) than GSD but the anteversion angles were similar between two breeds. The intracortical and extracortical dimensions of the cross-sections were generally bigger in KD than it were in GSD except that the medio-lateral dimensions at the isthmus and at the mid-shaft, the intracortical width of midshaft in cranio-caudal direction and extracortical width the lesser trochanter level in the medio-lateral direction (Table 1).

The cortico-medullary indices of all the dogs on the metaphyseal region were ranged 0.10-0.16 and 0.14-0.20, in medio-lateral and cranio-caudal directions, respectively. These indices were obviously high in both directions of the isthmus and midsaft regions that they were between 0.29-0.39 and 0.27-0.35 in medio-lateral and cranio-caudal directions, respectively. The GSD have significantly higher cortico-medullary indices than KD in the medio-lateral direction on the distal and proximal levels of the lesser trochanter and the cranio-caudal direction at the distal level of lesser trochanter of the bone. There was a similarity in cortico-medullary indices for the both breeds at the isthmus and midshaft regions (Table 2).

Table 1. The direct angle (°) and lenght (mm) measurements and the p-values to comparison between two breeds.

Tablo 1. İki köpek ırkı femurlarında direkt ölçülen açı (o) ve uzunluk (mm) verilerinin karşılaştırması.

			GSD	KD	Total	p
		Femoral length	198.33±16.09	236.64±21.29	217.49±26.89	.000
		Neck-shaft angle	145.13±4.77	150.05±3.99	147.59±5.00	.004
		Anteversion angle	17.78±10.54	19.74±9.47	18.76±9.90	.583
		Isthmus position	84.59±7.48	107.38±12.95	95.99±15.56	.000
Intracortical Widths	**M/L**	the proximal border of lesser trochanter	25.00±3.76	29.00±4.01	27.00±4.33	.013
		the lesser trochanter	23.82±4.31	26.91±3.73	25.36±4.26	.038
		the distal border of the lesser trochanter	20.09±3.83	23.86±4.16	21.98±4.37	.012
		isthmus	10.24±1.96	10.80±2.14	10.52±2.04	.447
		mid-shaft	11.24±2.09	11.70±2.58	11.47±2.32	.706
	Cr/Ca	the proximal border of lesser trochanter	15.80±2.49	19.03±2.28	17.42±2.86	.001
		the lesser trochanter	15.87±2.20	19.18±3.36	17.53±3.26	.003
		the distal border of the lesser trochanter	14.77±2.05	18.33±2.83	16.55±3.03	.000
		isthmus	10.38±1.98	12.10±2.46	11.24±2.36	.037
		mid-shaft	11.44±2.29	12.73±2.24	12.09±2.32	.119
Extracortical Widths	**M/L**	the proximal border of lesser trochanter	28.76±3.69	31.99±3.94	30.38±4.10	.023
		the lesser trochanter	27.55±4.38	30.55±3.96	29.05±4.38	.052
		the distal border of the lesser trochanter	23.82±3.90	26.49±3.23	25.16±3.77	.044
		isthmus	15.45±1.83	16.53±1.91	15.99±1.92	.112
		mid-shaft	16.03±2.01	17.05±2.32	16.54±2.20	.198
	Cr/Ca	the proximal border of lesser trochanter	18.99±2.71	22.06±2.19	20.52±2.88	.001
		the lesser trochanter	19.24±2.87	22.73±2.87	20.98±3.33	.001
		the distal border of the lesser trochanter	18.36±2.36	21.78±2.55	20.07±2.98	.000
		isthmus	15.43±2.26	17.95±2.39	16.69±2.62	.005
		mid-shaft	15.93±2.44	18.06±2.28	17.00±2.56	.016

The data are presented as mean value ± standard deviation. M/L; Medio-lateral, Cr/Ca; Cranio-caudal

Verilier ortalama değerler± standart sapma olarak sunuldu. M/L; Medio-lateral, Cr/Ca; Cranio-caudal

The isthmus region was 42.72% - 45.36% distally of the tip of femur in the dog. The isthmus position indices are higher on KD than on GSD (Table 2).

The canal flare index were calculated as 2.47 - 2.74 and 1.50-1.64 in medio-lateral and cranio-caudal directions, respectively. The metaphyseal canal flare index were also calculated as 1.20 - 1.28 and 1.03-1.08 in medio-lateral and cranio-caudal directions, respectively. The flare indices of proximal medullary canal remained non-significant across breeds, as well.

Discussion

When examining the repeatability of the current study, the values of the coefficients of variation ranged from 0.56% for the neck-shaft angle to 4.94% for the medio-lateral intracortical width at the isthmus. It was concluded that the measurement methods of the study was sufficiently accurate for this study (Ozdamar, 2015).

The isthmus position, the cortico-medullary and the canal flare indices were used in this study. They are the most useful data for preoperative planning or postoperative evaluating of the femoral implant on THA studies. They are also easy to use to evaluate objectively proximal femoral geometry (Abadie et al., 2010; Breusch, 2005; Noble et al., 1988; Palierne et al., 2006; Palierne et al., 2008) as well as to assess cortical bone quality (Baumgartner et al., 2015; Yeung et al., 2006).

The isthmus position index shows the level of the isthmus. The ideal stem length of femoral implant is defined by this index (Palierne et al., 2006; Palierne et al., 2008). The improper length of stem can lead to loosening or displacement of the cement plug into distal medullary canal (Noble et al., 1988). The postoperative fracture risk also may increase with misplacement of the tip of stem because femoral fractures associated THA are mostly occurred near the stem tip related incorrect loading of this region (Liska, 2004). The isthmus was placed between 42.72% and 45.36 % below the top of dog femora in present study. These values is in the range as described by Palierne et al. 2006, Palierne et al. 2008 in the dogs. There is a statistically significant difference between the levels of the isthmus in the two breeds. The isthmus is located about 6% higher in GSDs than in KDs. The level of isthmus can also be shown differences by race in human (Yang et al., 2014). According to our study results, it must be considered to stem design that the level of the isthmus might also change in different conformation of dogs breeds.

Table 2. The calculated indices and the p-values to comparison between two breeds.

Tablo 2. İki köpek ırkı femurlarında hesaplanan oran değerlerinin karşılaştırması.

		Indices	GSD	KD	Total	p
Cortico-medullary indices	M/L	the proximal border of lesser trochanter	0.13±0.03 (0.11-0.15)	0.09±0.03 (0.08-0.11)	0.11±0.04 (0.10-0.13)	.004
		the lesser trochanter	0.14±0.04 (0.12-0.16)	0.12±0.03 (0.10-0.14)	0.13±0.04 (0.12-0.14)	.164
		the distal border of the lesser trochanter	0.16±0.05 (0.13-0.18)	0.10±0.08 (0.06-0.15)	0.13±0.07 (0.10-0.16)	.016
		isthmus	0.34±0.07 (0.30-0.38)	0.35±0.07 (0.30-0.38)	0.35±0.07 (0.31-0.39)	.709
		mid-shaft	0.30±0.07 (0.27-0.34)	0.32±0.07 (0.28-0.36)	0.31±0.07 (0.29-0.33)	.514
	Cr/Ca	the proximal border of lesser trochanter	0.17±0.05 (0.14-0.20)	0.14±0.03 (0.12-0.16)	0.15±0.04 (0.14-0.17)	.058
		the lesser trochanter	0.17±0.05 (0.14-0.20)	0.16±0.06 (0.13-0.19)	0.17±0.06 (0.15-0.19)	.533
		the distal border of the lesser trochanter	0.20±0.04 (0.17-0.22)	0.16±0.05 (0.14-0.19)	0.18±0.05 (0.16-0.20)	.019
		isthmus	0.33±0.06 (0.32-0.37)	0.33±0.06 (0.30-0.36)	0.33±0.06 (0.31-0.35)	.982
		mid-shaft	0.29±0.06 (0.25-0.32)	0.30±0.05 (0.27-0.32)	0.29±0.06 (0.27-0.31)	.534
CFI		**M/L**	2.48±0.39 (2.28-2.69)	2.73±0.31 (2.56-2.89)	2.61±0.37 (2.47-2.74)	.060
		Cr/Ca	1.54±0.20 (1.44-1.65)	1.60±0.19 (1.50-1.70)	1.57±0.19 (1.50-1.64)	.410
MCFI		**M/L**	1.26±0.11 (1.20-1.31)	1.23±0.12 (1.16-1.29)	1.24±0.11 (1.20-1.28)	.468
		Cr/Ca	1.07±0.08 (1.02-1.11)	1.04±0.07 (1.01-1.08)	1.06±0.07 (1.03-1.08)	.341
Isthmus position index			42.67±2.07 (41.57-43.77)	45.41±4.42 (43.05-47.76)	44.04±3.67 (42.72-45.36)	.032

The data are presented as mean value ± standard deviation and 95% confidence intervals, M/L; Medio-lateral, Cr/Ca; Cranio-caudal

Verilier ortalama değerler± standart sapma ve 95% güven aralığı olarak sunuldu, M/L; Medio-lateral, Cr/Ca; Cranio-caudal

The cortico-medullary index shows the cortical thickness which may influence the design of canal-fill within the femoral stem component (Palierne et al., 2006). Other side cortical thickness is an important factor to proper canal preparation (Peck and Marcellin-Little., 2013) In studies about THA, the cortico-medullary index is generally calculated only at the midshaft or at the ishtmus regions and at the medio-lateral direction (Baharuddin et al., 2014; Noble et al., 2003; Palierne et al., 2006; Palierne et al., 2008; Umer et al., 2010; Yeung et al., 2006). Femur has under the bending loadings in particularly. However, the direction of greatest resistance to bending is nearly aligned with the medio-lateral anatomical axis proximally and progressively becomes more aligned with the cranio-caudal axis distally (Sumner and Devlin, 1990). Therefore the cortico-medullary index in both directions showed some variations among the different levels of the proximal femur in this study. The thickest cortex was at the isthmus level whilst the thinnest was at proximal metaphyseal level for both directions of all dogs. The thickness of the cortex was rising about three times from the proximal extremity to the isthmus in medio-laterally direction whereas it is just about twice thicker in cranio-caudal direction. The GSD has shorter bones than KD but they have similar cortical thickness at the midshaft and the isthmus regions in particular. Therefore, when designing new implants, choosing proper implant before surgery and preparing bone beds to place implant, it may be taken into consideration that the cortical thickness may show some variations among the regions as well as among the different breeds of dogs.

The proximally flare of the medullary canal of femur is described as the canal flare index which is the most used parameter in the THA studies (Abadie et al., 2010; Breusch, 2005; Noble et al., 1988; Noble et al., 2003; Palierne et al., 2006; Palierne et al., 2008; Rashmir-Raven and DeYoung, 1992; Tawada et al., 2015; Umer et al., 2010). It is well- known that any deviation from the normal index can lead to subsidence risk or postoperative fracture risk (Conzemiuus and Vandervoort, 2005; Ganz et al., 2010; Rashmir-Raven and DeYoung, 1992). CFI is also used to define the implant type before operation (Husman et al., 1997; Noble et al., 1988; Peck et al., 2013; Tawada et al., 2015). The CFI was firstly defined for human femora by Noble as the ratio of the medio-lateral medullary diameter at the proximal extremity of the lesser trochanter to the medio-lateral medullary diameter of the isthmus (Noble et al., 1998). Although there are some studies, there is no consistency about standard values and the calculation methods of CFI in dog femora. Palierne et al (2006-2008) calculated the CFI as the ratio between the intracortical width at the proximal level of lesser trochanter point and at the isthmus. We used the Palierne's and Noble's method to calculate the CFI. Marcellin-Little et al. (1999), Ganz et al. (2010) and Pugliese (2014) calculated as the ratio between the intracortical width at the level of lesser trochanter point and at the isthmus. Rashmir-Raven and DeYoung (1992) calculated as the ratio between the intracortical width at the level of lesser trochanter point and at the mid-shaft. The 95% confidence intervals of CFI of this study in medio-lateral direction were between 2.47 and 2.74 in this study. These data are in the range of Palierne's data for CFI. Rashmir-Raven and DeYoung (1992) indicated that the breed of dog may be an important determinant of canine femoral morphology according to their clinical experience. They indicated that, the GSD frequently have a stovepipe appearance of femur. Ganz et al. (2010) also indicated that GSD has lower CFI. Understanding from these studies, it is just a presuming not any statistical evidence. Pugliese (2014) was measured the mean CFI values on three dog breeds and they found that CFI values were significantly lower in GSD than the others. At the studies of Palierne et al., the CFI of dog femur was found very homogenous and the size was not correlated the shape of the femur like the CFI (Palierne et al., 2006; Palierne et al., 2008). In our study no statistically difference was observed in the CFI among GSD and KD femora. These values confirm the findings of Palierne et al. (2008). The KD have longer femur than the GSD whilst there was no statistical difference between CFI values of the two breeds in this study.

The supplementary data of canal flare is important to support other morphometric data. Because, good metaphysical stem fit is considered to be one of the major goals to optimize metaphyseal load transfer in cemented or cementless femoral stem, and each also may be selected according to the metaphyseal shape (Noble et al., 1998; Umer et al., 2010; Yang et al., 2014). Therefore the metaphyseal canal flare index was also considered in this study. This index was between 1.20 and 1.28 on the dogs of this study and this is also in the range already described by Palierne et al. 2006 and Palierne et al. 2008. On the other side, the variations of flare of proximal femoral canal on cranio-caudal direction require the designing of the anatomic femoral implants or other biologic fixation implants which are often used in human orthopedics (Baharuddin et al., 2014; Husman et al., 1997; Laine et al., 2000; Rubin et al., 1992; Yang et al., 2014). The cranio-caudal radiographs have been only used to calculate the CFI for dog femora (Ganz et al., 2010; Marcellin-Little et al., 1999; Palierne et al., 2006; Palierne et al., 2008; Pugliese, 2014; Rashmir-Raven and DeYoung, 1992). The flare of the medullary canal was evaluated with the cranio-caudal diameters on three-dimensional images in our study. The cranio-caudal canal flare index of dog was between 1.50 and 1.64. The cranio-caudal metaphyseal canal flare index of dog was also between 1.03 and 1.08. As far as we know there is no data about the flare of canine proximal femur in cranio-caudal direction.

A limitation of this study, the body weight may not been considered as a morphological parameter because the weight of some dogs was only estimated. The length and diameters of bone may be used as descriptive properties of dogs. Another limitation of this study, we used the mature bones but the exact age of some dogs were not known. The age-related remodelling changes might alter the proximal femoral morphology. There is no deal about the relation of age and proximal medullary canal shape of dog. According to their clinical experience, Rashmir-Raven and DeYoung (1992) stated that the shape of the proximal femur relevant to age. In contrast, Pugliese (2014) did not find any statistical relationship between CFI and the age of the dog. Only two breeds of dog could be used in this study because there was no enough bone from the other breeds to provide the study conditions. The GSD and KD were used in this study that they have distinct pelvic limb conformation with different angles of joints (Sabancı, 2015). Only the healthy femora were used in this study is the other limitation. It is well known that some morphometric changes could be observed on extremely osteoarthritic femur which indicated in human being studies (Noble et al., 2003; Sugano et al., 1998) The future morphometric studies are required using these methods in the different age of dog femora with deformity.

In conclusion, the three morphometric index data have been evaluated to indicate the detailed geometry of the proximal femoral canal of dog using three-dimensional morphometric methods to provide a database for the THA studies. According to our study results, it must be considered to stem design that the level of the isthmus might also change in different conformation of the dogs breeds whilst the flare indices are similar. The cortico-medullary index shows some variations in the dog breeds among the level and the directions of the cross-sections of the proximal femur. The flare of the medullary canal was firstly evaluated with the cranio-caudal diameters on the three-dimensional images in our study. Nowadays, three-dimensional images can be achieved and morphometric measurements can be also done easily by tomography on a lot of veterinary clinics. The data of three-dimensional morphometric analysis may contribute to the optimization of the design and preoperative selection of femoral implant for surgeons.

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