Three Dimensional Morphometry of Proximal Femur to Design Best-Fit Femoral Stem for Indonesian Population

Morfometría Tridimensional del Fémur Proximal para Diseñar Prótesis a Medida en la Población de Indonesa

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SUMMARY: To design custom-made prosthesis in a certain population, the morphometry needs to be measured. The results of this study were expected to provide basic data to design the ideal size of the total hip arthoplasty prosthesis for Indonesian population. This was an anthropometric study conducted on sex matched 100 healthy Indonesian mongoloid race subjects based on Computer Tomographic (CT) imaging on the proximal femur. The parameters being used in this study were Femoral Head Offset (FHO), Femoral Head Position (FHP), Femoral Head Diameter (FHD), Neck-Shaft Angle (NSA), Anteroposterior Width (APW) and Mediolateral Width at 3 different locations, and Canal Flare Index (CFI). This study showed that Indonesian has smaller proximal femur morphometry as compared to Western population. The mean value of all parameters in male were larger than female. Moreover, FHO and FHP showed significant difference among male and female indicating the location of male femoral head center lies superiorly as compared to female. The dimension of femoral canal was found to be mediolaterally oval, 1.43, 1.28, and 1,34, respectively, in 3 different cutting (20 mm above and 40 mm below lesser trochanter, and isthmus). CFI of Indonesian was classified to be stovepipe femoral canal (2.99) that is the suggestion to use cemented femoral stem. This study showed that Indonesian proximal femur dimension has smaller build compared with Western counterpart. The proposed dimensions can be used as the basic data to design the ideal size of the femoral stem for Indonesian population.

KEY WORDS: Proximal femur morphometry; Computed tomography; Femoral stem; Indonesian population.

INTRODUCTION

In order to achieve maximal outcome of Total Hip Replacement (THR) procedures, well suited implant based on the proximal femur morphology in certain population should be made. Mismatched prosthesis or inappropriate placement of the prosthesis can lead to loosening of the prosthesis and unbalance weight distribution, and it will affect the functional outcome post operatively (McGrory *et al.*, 1995). Bony growth into the prosthesis would be optimal when proper fit prosthesis is used which will result in long term fixation and stability (Casper *et al.*, 2012). Undersizing stem disturbs the osteointegration process and oversizing stem lead to periprosthetic fracture due to sliding down of the stem that is too large inside the bone (Søballe *et al.*, 1992; Berry, 2000). Micromotion can also happen at the bone-stem interface in the early days after stem implantation which can disturb trabeculae bone ingrowth. Aseptic loosening, osteolysis, and thigh pain might eventually occur due to this micromotion (Reddy *et al.*, 1999). Improper load distribution that is transferred along the bone and stem due to differences in geometric measurements cannot prevent stress shielding. In contrast, well matched prosthesis to the internal femoral shape transfer 70—90 % forces, where distal prosthesis that support stress at the metaphysis give benefit to diaphysis (Jasty *et al.*, 1998). Therefore, the measurement of proximal femur morphometry in a certain population is strongly needed.

Differences in genetics, lifestyle, applied force and their distribution affect the build and stature size between ethnicity as shown in several studies (Hoaglund & Low,

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1980; Igbigbi & Msamati, 2002; Baharuddin *et al*., 2011). Based on some studies, it showed that the eastern population has relatively smaller measurement compared with Western population. However, currently most of the prosthesis used in Indonesia were designed based on the measurements of Western population. In addition, awareness of sex specific implants is increasing due to the differences. Nelson & Magyesi (2004) studied the difference between male and female bone architecture and showed that male has larger build and stature compared with female.

This study was an anthropometric analysis on proximal femur obtained from normal Indonesian hip using three dimensional computer tomographic measurements. The results of the measurement were expected to provide basic data to design the ideal size of total hip arthoplasty prosthesis for South East Asian population in general and for Indonesian population specifically.

MATERIAL AND METHOD

Subjects. This was a descriptive analytic study conducted on sex matched 100 healthy Indonesian mongoloid race subjects with Javanese ethnicity. The subjects were 20 to 70 years old. The inclusion criteria of this study were subjects with normal alignment of the lower extremity, absence of neuromuscular deformity and abnormality, absence of signs and symptoms of the hip arthritis, and independent daily activities performed by the subjects. The researchers selected the subjects by random sampling from the population of Indonesian mongoloid race lived in Yogyakarta, Indonesia. Information regarding this study was well delivered to those eligible subjects and consent was taken. This study was approved by ethical committees from Faculty of Medicine Universitas Gadjah Mada. Measurement of the proximal hip morphometry parameters was using right hip of the subjects.

Computer tomographic (CT) technique. The proximal hip morphology in this study was measured based on Computer Tomographic (CT) imaging using CT-Scan Phillips ingenuity core 128, 128 slices 120 kvp, 2.0 mm. The subjects were asked to lie in supine position with the lower extremity in anatomical position. The retrieved image was formed in the file shape of DICOM 3.0, it was then reconstructed into 3D image with Phillips Intelli space portal CT viewer version 4.0.0.1921 software that was integrated with the CT Scan. The proximal femur 3D model image was 360 degree rotatable, could be cut and measured into desired area.

Proximal femoral cuts and morphometry measurements. The parameters of proximal femur being used in this study

were Femoral Head Offset (FHO), Femoral Head Position (FHP), Femoral Head Diameter (FHD), Neck Shaft Angle (NSA), Anteroposterior width at section 1 (APW1), Mediolateral width at section 1 (MLW1), Anteroposterior width at section 2 (APW2), Mediolateral width at section 2 (MLW2), Anteroposterior width at section 3 (APW3), and Mediolateral width at section 3 (MLW3). FHO was measured as the line drawn from femoral head center to the femoral shaft axis, and the measurement of femoral head center position based on the lesser trochanter was called FHP. FHD was the maximum diameter of the femoral head. FNSA was the angle that was formed between femoral neck axis and femoral shaft axis. For APW and MLW, the proximal femur was cut at 3 levels perpendicular to femoral anatomical axis. First measurement or APW1 and MLW1 were measured 20 mm above lesser trochanter, second measurement or APW2 and MLW2 were measured 40 mm below lesser trochanter, and the third measurement or APW3 and MLW3 were measured at isthmus section. APW was portrayed as the proximal femur anteroposterior dimension and drawn as the longest anteroposterior length of the proximal femur cut surface, meanwhile the MLW portrayed the mediolateral aspect of the cut surface and it was drawn as the perpendicular line that passed through the midpoint of APW line in each cut surface.

Independent T test was used to analyze the proximal femur morphology between male compared with female subjects and Pearson correlation test was used to determine the correlation between variables. Proposed dimension of the proximal femur components was calculated based on 25, 50, and 75 percentile of the data. Values for $p < 0.05$ was regarded as statistically significant.

RESULTS

We studied the morphology of proximal femur of 100 normal knee with equal number of male and female. The mean of age was 49.9 years and it was not significantly different between male and female subjects with p value 0.767. All the subjects in this study did not have severe changes in the hip. Table I showed the mean of all parameters measured in this study. The comparison of parameter measurement result in this study and other studies conducted in several countries was shown in Table II.

This study showed that there were significant differences between male and female in 6 out of 10 parameters measured. There were FHO, FHP, FHD, APW1, MLW1, and APW2. However, the CFI showed similar proportion between male and female (Table III). AP and ML

Table I. Morphology of proximal femur in all sex subjects.

|	n	Min.	Max.	Median	Mean±SD	95% CI for mean (lower – upper)
Age	100	20	73	55	49.95±15.71	46.83–53.07
FHO	100	22.90	52.30	35.40	35.18±5.24	34.13–36.22
FHP	100	39.10	73.90	53.65	53.77±7.70	52.24–55.30
FHD	100	38.30	53.50	45.70	45.35±3.82	44.59–46.11
NSA	100	110.00	139.00	128.00	127.91±4.96	126.92–128.89
APW_1	100	21.40	42.00	29.95	30.14±3.58	29.43–30.85
MLW_1	100	32.60	72.70	42.60	43.09±5.47	42.01–44.18
APW_2	100	7.90	19.10	12.60	12.83±2.28	12.38–13.29
MLW_2	100	10.80	23.00	16.20	16.40±2.69	15.87–16.94
APW_3	100	7.50	18.00	11.05	11.10±1.91	10.72–11.48
MLW_3	100	10.30	23.10	14.60	14.79±2.71	14.25–15.33
CFI	100	1.70	5.3	2.95	2.99±0.60	2.87–3.11
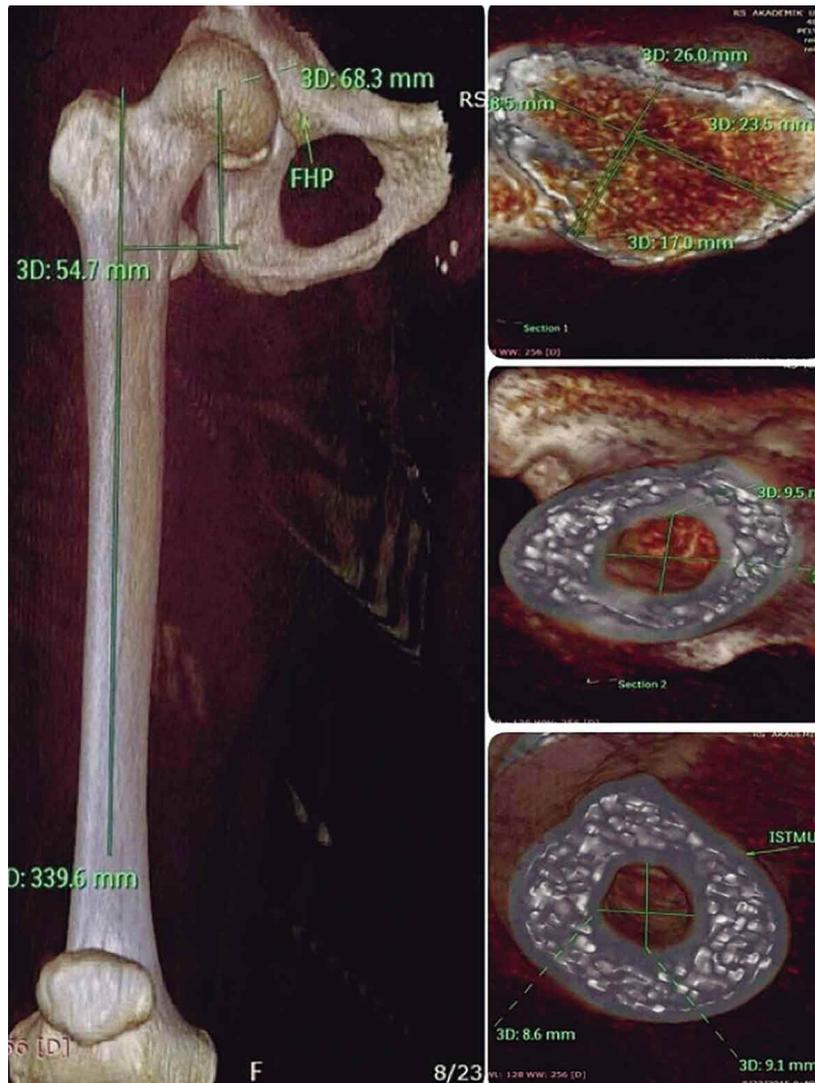
Fig. 1. Three dimensional CT image of the proximal femur showing the parameters used in this study.

were measured in 3 different locations. The morphological relationship between femoral head position from lesser trochanter and femoral head offset was shown in Figure 2. Figure 3 showed the variation of mean ML and AP canal width where it revealed that the AP and ML at 20 mm above lesser trochanter was larger compared at isthmus and 40 mm below lesser trochanter in terms of size. Figure 4 showed aspect ratio of ML canal width per AP canal width at 3 different locations among male, female, and all subjects. The proposed dimensions of the proximal femoral components for hip prostheses were seen in Table IV.

Table II. Summary of the proximal femur morphometry reported in different studies.

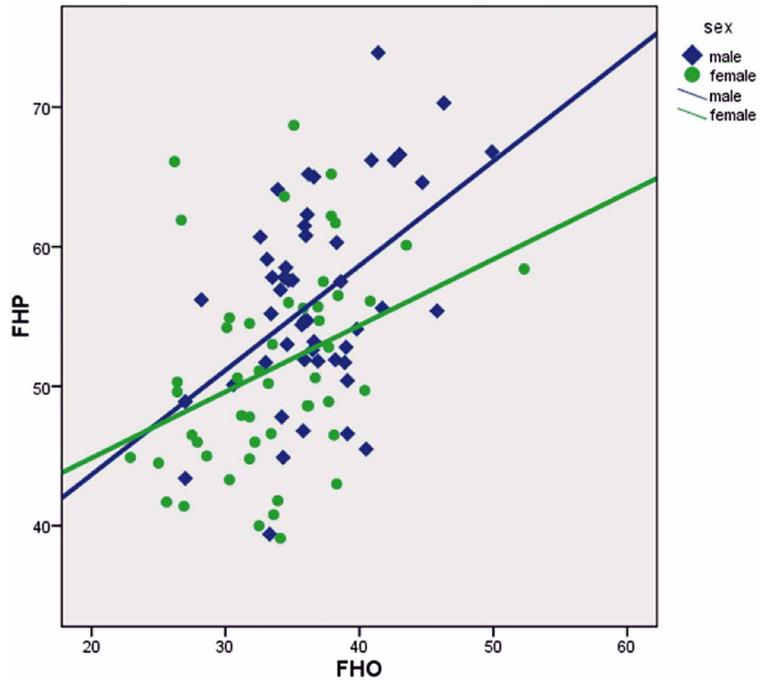|	Husmann et al. (1997) (n=310)	Rubin et al. (1989) (n=32)	Noble et al. (1989) (n=80)	Saikia et al. (2008) (n=98)	Mishra et al. (2009) (n=50)	Umer et al. (2010) (n=136)	Mahaisavariya et al. (2002) (n=108)	Baharuddin et al. (2011)	This Study
Population	France	Swiss	Caucasian	Indian	Nepalese	Pakistan	Thai	Malaysia	Indonesia
FHO	40.5±7.5	47±7.2	---	40.23±4.85	---	41.9±6.9	---	30.35±4.26	35.18±5.24
FHP	57.3±8.1	56.1±8.2	---	52.33±7.19	---	56.0±6.5	48.94±4.95	53.14±4.87	53.77±7.70
FHD	---	43.4±2.6	45.9	45.41±3.66	44.26±3.58	50.1±3.8	43.98±3.47	40.81±3.43	45.35±3.82
NSA	129.2±7.8	122.9±7.6	125.4	124.42±5.49	---	130.3±6.1	128.04±6.14	---	127.91±4.96
APW$_1$	38.2±7.3	---	---	26.26±3.7	---	---	---	---	30.14±3.58
MLW$_1$	46.3±6.9	43.1±5.2	51.5	36.78±5.32	---	47.4±4.8	---	---	43.09±5.47
APW$_2$	19.7±3.0	---	---	---	---	---	---	---	12.83±2.28
MLW$_2$	19.3±2.9	---	---	---	---	---	---	---	16.40±2.69
APW$_3$	14.2±2.9	---	---	11.47±2.11	---	---	---	---	11.10±1.91
MLW$_3$	11.2±2.3	13.1±2.1	12	9.02±1.92	---	---	10.5±1.81	---	14.79±2.71

Fig. 2. The morphological relationship between femoral head position and femoral head offset based on sex.
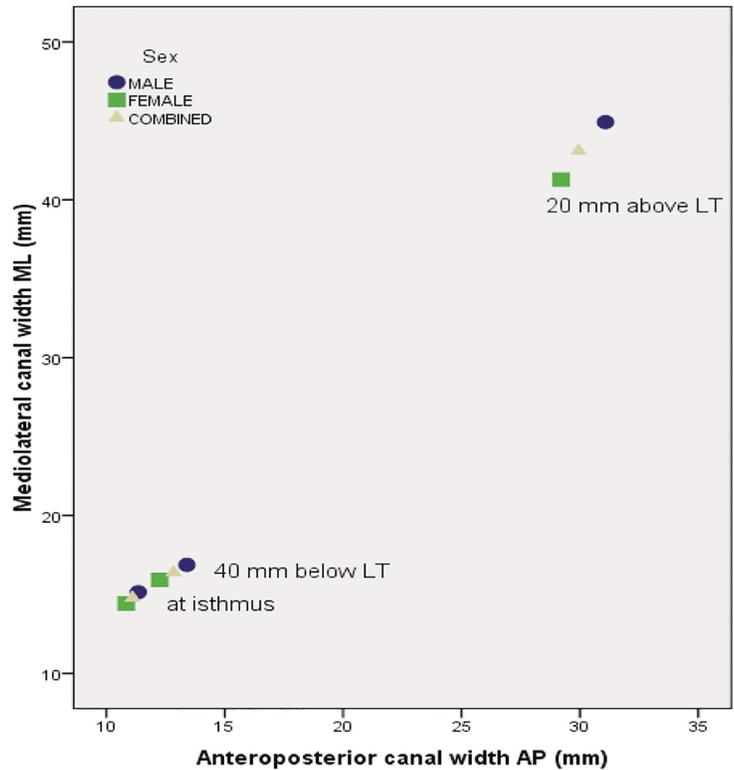

Fig. 3. Average ML canal width versus AP canal width at different positions.

Table III. Descriptive statistic and comparison between male and female subjects (mm).

	Sex	*n*	Mean±SD	SE Mean	Mean Difference	95% CI for difference (lower – upper)	Sig. (2-tailed)
FHO	Male	50	36.78±4.59	0.64942	3.21	1.22–5.20	0.002
	Female	50	33.57±5.40	0.76409			
FHP	Male	50	56.24±7.27	1.02830	4.93	2.02–7.84	0.001
	Female	50	51.30±7.39	1.04523			
FHD	Male	50	47.22±3.24	0.45822	3.73	2.39–5.06	0.000
	Female	50	43.49±3.46	0.49053			
NSA	Male	50	128.10±4.42	0.62548	0.28	-1.59–2.36	0.704
	Female	50	127.72±5.48	0.77620			
APW_1	Male	50	31.08±3.36	0.47578	1.87	0.49–3.25	0.008
	Female	50	29.21±3.57	0.50581			
MLW_1	Male	50	44.91±5.92	0.83754	3.63	1.57–5.69	0.001
	Female	50	41.27±4.32	0.61199			
APW_2	Male	50	13.40±2.53	0.35886	1.15	0.26–2.02	0.012
	Female	50	12.26±1.86	0.26380			
MLW_2	Male	50	16.88±2.72	0.38486	0.95	-0.10–2.00	0.077
	Female	50	15.93±2.60	0.36776			
APW_3	Male	50	11.35±1.90	0.26953	0.51	-0.25–1.27	0.183
	Female	50	10.84±1.91	0.27095			
MLW_3	Male	50	15.15±2.85	0.40423	0.72	-0.35–1.79	0.187
	Female	50	14.43±2.54	0.36037			
CFI	Male	50	3.06±0.67	0.09527	0.132	-0.106–370	0.275
	Female	50	2.93±0.51	0.51794			

Table IV. Proposed dimension of the proximal femur components in hip prostheses.

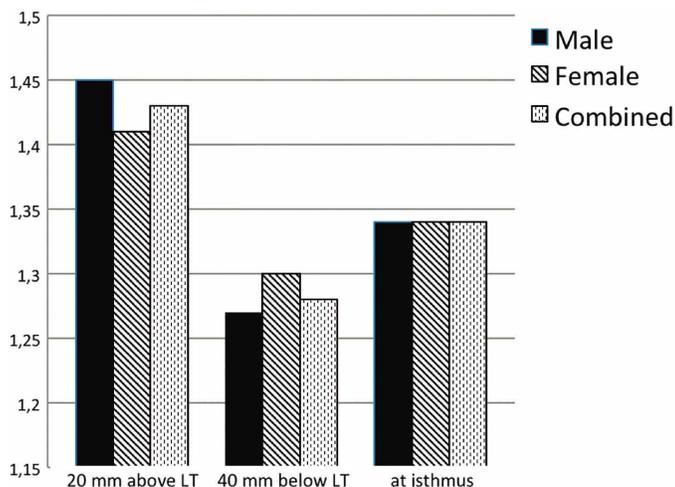|		FHO	FHP	FHD	NSA	APW_1	MLW_1	APW_2	MLW_2	APW_3	MLW_3	CFI	Mlper AP$_1$	Mlper AP$_2$	Mlper AP$_3$
n		100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentile	25	32.50	47.82	42.20	125.00	27.77	39.77	11.12	14.52	9.80	12.82	2.60	1.34	1.17	1.24
	50	35.40	53.65	45.70	128.00	29.95	42.60	12.60	16.20	11.05	14.60	2.95	1.42	1.29	1.33
	75	38.17	58.47	47.97	131.00	32.57	46.32	13.90	18.62	12.27	16.17	3.40	1.50	1.38	1.40

Fig. 4. Comparison of aspect ratio (MLW/APW) in 3 different positions of proximal femur.

DISCUSSION

Well-suited implant will lead to better outcome, therefore, it is necessary to design custom made prosthesis based on certain population morphometry. Several studies showed that Asian population have a smaller build and stature compared with Western population. We tried to compare the results of our study with other studies conducted in several countries either using CT Scan or X-ray based measurement on proximal femur. Our study showed that Indonesian population has smaller femoral head dimension compared with Western population (Noble *et al*., 1988; Rubin *et al*., 1989; Hussmann *et al*., 1997). However, among southeast Asian, such as Thai and Malaysian, our study showed that Indonesia has larger femoral head morphometry (Baharuddin *et al*.; Mahaisavariya *et al*., 2002). Extramedullary dimensions (femoral head position, femoral head offset, and ante version angle) play an important role in maintaining proper hip kinematics and it will affect the satisfaction of post-operative result (Sugano *et al*., 1999; Ranawat & Rodriguez, 1997).

The difference in hip shape and load distribution between male and female might affect the differences in the morphometry measurement as shown in this study where male showed larger measurement compared with female (Rawal *et al*., 2012). Moreover, earlier research conducted by an anthropologists in 17th centuries showed that there were differences in the head femur measurement between sexes (Gomez & Morcuende, 2005). Among sex, this study reflected the morphological relationship between FHP and FHO in Figure 2 and it showed that FHO and FHP only have moderate relationship based on Pearson correlation statistics. Compared to another study conducted by Baharuddin *et al*., similar results were shown. They showed that FHO and FHP did not have correlation.

The size of femoral canal dimension should be taken into account to provide primary stability during the design evolution stage (Rawal *et al*.). A big gap was seen in Figure 3 between measurement result at 20 mm above lesser trochanter and 40 mm below lesser trochanter. It showed that Indonesian has quite larger femoral canal size at 20 mm above lesser trochanter compared with the measurement in the isthmus and 40 mm below lesser trochanter. To predict the shape of the anticipated femoral stem, this study measured the aspect ratio of proximal femur at 3 different locations. ML per AP canal width can predict the shape of proximal femur transversely. Figure 4 indicates that the shape of proximal femur aspect ratio was mediolaterally oval, the most mediolaterally oval was seen in 20 mm above lesser trochanter, and it was relatively similar between male and female.

CFI is one of important parameters to design well-matched prosthesis because it defines frontal plane proximal femur morphology. This study showed that mean CFI for Indonesian population was 2.99. Because it was lower than 3, Indonesian have stovepipe femoral canal (3-5 is normal; >5 is champagne-fluted). Based on Fessy *et al*. (1997) stovepipe femoral canal suggest the use of cemented femoral stem in hip arthoplasty procedure. However, this study did not compare the CFI in terms of age, even though CFI decreased with age due to cortical bone loss. Decrease in the cortice will eventually cause isthmus width increase and lead to overall flare decrease (Casper *et al*.).

This study was expected to be the basic data for further study in designing femoral stem implant for Indonesian population. In order to achieve well-matched femoral stem and good functional outcome post operatively. Further study based on wider variety of sample selection of Indonesian mongoloid races is needed and this study can guide the development of total hip prosthesis for Indonesian population.

CONCLUSION

The anthropometric data on proximal hip morphometry of Indonesian population showed that Indonesian people have smaller build compared with Western counterpart. This study may provide guidance for designing well matched hip prosthesis for Indonesian population based on the dimension proposed in this study.

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RESUMEN: Para diseñar prótesis a medida en una población determinada, la morfometría necesita ser conocida. El objetivo de este estudio fue obtener resultados que sean útiles en la investigación para diseñar el tamaño ideal de una prótesis total de artroplastía de cadera para la población de Indonesia. Fue realizado un estudio antropométrico en 100 sujetos sanos de raza mongoloide de Indonesia, en los que se estudió la parte proximal del fémur por tomografía computadorizada

(TC). Se consideraron como parámetros la cabeza del fémur (CF), posición de la cabeza del fémur (PCF), diámetro de la cabeza del fémur (DCF), ángulo cérvicodiafisario (ACD), ancho anteroposterior (AAP) y ancho-lateral en 3 lugares diferentes. La población Indonesia tiene una morfometría menor del fémur proximal en comparación con la población occidental. El valor medio de todos los parámetros en hombres fueron mayores a las mujeres. Por otra parte, CF y PCF mostraron diferencia significativa entre hombres y mujeres e indicó una ubicación superior del centro de la cabeza del fémur en hombres, en comparación con las mujeres. Se encontró que la dimensión del canal femoral fue mediolateral oval, 1,43, 1,28, y 1,34, en 3 cortes diferentes, respectivamente (20 mm superior y 40 mm inferior del trocánter menor e istmo). La dimensión del fémur proximal en la población de Indonesia es de menor tamaño en comparación con la contraparte occidental. Las dimensiones propuestas se pueden utilizar como datos básicos para el diseño de un tamaño ideal de vástago femoral para la población Indonesia.

PALABRAS CLAVE: Morfometría de femur proximal; Tomografía computadorizada; Vástago femoral; Población Indonesia.

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