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Morphologic differences in the bone cuts of the knee between Han Chinese and Mongolian Chinese and their correlation with current knee prostheses

Qida <u>Zhang</u>[1], PhD, Zhifeng <u>Zhang</u>[1,2], BSc, Zhenxian <u>Chen</u>[3], PhD, Jiayu <u>Hu</u>[1], PhD, Yusheng <u>Qiu</u>[2], MD, Zhongmin <u>Jin</u>[1,4,5], PhD

[1]State Key Laboratory for Manufacturing System Engineering, School of Mechanical Engineering, Xi'an Jiaotong University, [2]Department of Arthroplasty Surgery, the First Affiliated Hospital of Xi'an Jiaotong University, [3]Key Laboratory of Road Construction Technology and Equipment of MOE, Chang'an University, Xi'an, [4]Tribology Research Institute, School of Mechanical Engineering, Southwest Jiaotong University, Chengdu, China, [5]Institute of Medical and Biological Engineering, School of Mechanical Engineering, University of Leeds, Leeds, UK

Correspondence: Zhang Qida, School of Mechanical Engineering, Xi'an Jiaotong University, 710054 Xi'an, Shaanxi, China. zhangqida621@gmail.com

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INTRODUCTION

Total knee arthroplasty (TKA) is widely adopted to treat knee osteoarthritis and trauma for restoring the normal knee function.[1] Apart from the patient and surgical factors, the geometric matching of the properly designed knee prosthesis is crucial for its clinical success.[2-13] If the prosthesis is smaller than the resected surface of the distal femur and proximal tibia, it may lead to subsidence and loosening. In contrast, it may alter local soft tissue balance and cause soft tissue impingement, when the prosthesis is too larger than the resected surfaces.[14] Therefore, the morphology of resected knee is vital for designing an optimal knee prosthesis.[14]

Several studies have pointed out that most of the TKA prostheses designed on the basis of the anatomy of Caucasian are not suitable for Asian patients.[2,12,13] The Asian patients normally have a smaller knee than Caucasian patients.[7,8,15] Mahfouz et al[16] reported that there were significant differences in three-dimensional knee morphology among Caucasian, African American and East Asian populations. Li et al[15] found that ethnicity and gender differences of the resected femur and tibia surfaces existed between Chinese and Caucasian population. Even with more sizes of prostheses with smaller increments are not sufficient to address these problems, as the aspect ratios are different between the natural knee and the artificial knee implants.[12] Compared with the knee morphology of Asian patients, the aspect ratio, defined as the mediolateral (ML) dimension divided by the anteroposterior (AP) dimension, of most current knee prostheses used for Asian patients were not suitable.[2,11-13] Several studies have indicated that the ethnicity-specific prostheses could better meet the knee morphology of Asian populations.[1,2,7,8,11-13,17,18] Therefore, knowledge of the morphologic differences among varied ethnic groups is essential to improve the clinical outcomes of TKA. However, there is lack of comparative knee morphological studies between different Chinese ethnicities.

It is well-known that there are significant morphological differences between male knees and female knees.[1,9,12,15,19,20] An increasing number of evidence indicated that females

have smaller dimensions than male counterparts, and the standard prostheses often cause the mediolateral (ML) overhang in female patients.[9,15,19-23] Many studies have revealed that a gender-specific knee prosthesis is indispensable to better match the female or male patient's knee sizes.[1,8,10-13,24,25] Furthermore, currently available femoral and tibial prostheses do not perfectly match the entire Chinese male and female patients.[8,12,14,15,21] The perfect fit rates of femoral component were remarkably increased in both Chinese males and females using the gender-specific knee prostheses compared to the standard counterparts.[1] Therefore, the gender differences should be taken into account in the design of knee prostheses for Chinese men and women. However, the dimensional and morphological differences of knee joint in Han Chinese and Mongolian Chinese have still yet to be determined.

In this study, the knee morphological differences of the bone cuts in gender and ethnicity between Han Chinese and Mongolian Chinese were investigated. Meanwhile, dimensional comparison was made between the Chinese knees and typical knee prostheses. Furthermore, the morphological relationship between femur and tibia was also investigated in ethnicity and gender differences.

METHODS

A total of 74 normal knees, including 44 normal Han Chinese knees (26 males, 18 females) and 30 normal Mongolian Chinese knees (16 males, 14 females) were analysed in this study. The average age of the subjects was 36.0±7.2 years (23- 45 years). The normal Mongolian Chinese were recruited by the experienced surgeons from the Inner Mongolia Autonomous region of China, which is the main place where the Mongolian Chinese live. The Han Chinese were recruited by the experienced surgeons from the central China, which is the main place where the Han Chinese live. The subjects were excluded if they had a history of congenital

anomaly or femoral fracture, knee injury and other knee pathologies. This study was approved by institutional review board.

All the knees were scanned using a helical CT scanner imaging machine (Light Speed 16, GE Medical System, General Electric Company, USA) (120kVp; 320mA; 512*512 matrix; slice thickness, 0.625mm) after obtaining the informed consent of every volunteers. The subjects were placed supine in the scanner with both knees taped to the scanner platform in the extended position with the patella facing towards the ceiling. The scanning data were then imported into the Mimics medical imaging program (version 16.0; Materialise, Leuven, Belgium) for three-dimensional reconstruction of knee models, whereas the bony cuts and measurements were done under the guidance of an experienced surgeon using Geomagic studio program (version 12.0; Geomagic, USA).The morphologic data of five times repetitive measurements were used to calculate the average values for analysis.

The tibial mechanical axis was defined as the line connecting the center of knee and the center of the ankle.[26] The proximal tibia was cut perpendicular to the tibial mechanical axis by a 6 mm resection depth below the medial plateau with a 7°posterior slope[2] (Fig. 1 A1). The tibial mediolateral (tML) dimension was defined as the longest medial-lateral line of the proximal tibial cut surface. This line was drawn parallel and collinear to the epicondylar axis of the femur, which was defined by connecting the medial sulcus of the medial epicondyle, as described by Uehara et al.[17] The tibial middle anteroposterior (tAP) dimension was taken as the length of a line drawn passing through the midpoint of the tML line and perpendicular to the tML line. The tibial medial anteroposterior (tMAP) and tibial lateral anteroposterior (tLAP) dimensions were taken as the length of lines drawn parallel to the tAP and passing through the posterior-most points of the medial and lateral tibial condyles, respectively (Fig. 1 A2). The tibial aspect ratio (tML/tAP) was calculated to analyse the shape of the knee.

The femoral anatomic axis was defined as a line connecting the centre point of transepicondyles introcession and the centre point of the intramedullary canal at the distal third of the femur.[12] The distal femur was cut by a 9 mm resection depth above the lowest point of the medial condyle with 6° valgus relative to the anatomic axis[12] (Fig. 1 B1). The femoral ML axis was defined according to the most prominences of the medial and lateral femoral condyles. The femoral AP axis was perpendicular to the ML axis. The femoral mediolateral (fML) dimension was measured on the distal femoral cut surface in the ML axis direction. The femoral anteroposterior (fAP) dimension was taken as the total width of the lateral condyle in the AP axis direction.[12] The femoral medial anteroposterior (fMAP) and femoral lateral anteroposterior (fLAP) dimension were taken as the widest aspect of the medial and lateral condyles on the distal femoral cut surface in the AP axis direction (Fig. 1 B2). The femoral aspect ratio (fML/fAP) was calculated to analyse the shape of knee.

The measured femoral and tibial values were then compared with the corresponding morphology of four commonly used prostheses in China, Scorpio and Duracon (Stryker Howmedica Osteonics, Allendale, NJ), PFC sigma (DePuy-Johnson and Johnson, Warsaw, IN), and Nexgen (Zimmer, Warsaw, IN). Different sizes were obtained from a previous study reported by Cheng et al.[12] An appropriate TKA size was chosen for a given knee joint. All the tibial components of these products were symmetrical in ML direction.[12]

A statistical analysis was performed in the SPSS software 22.0 (SPSS, Chicago, IL). The above measured dimensions were presented as the mean ± standard deviation. The data analysis was performed by using the t-test, the independent sample t-test and Pearson's correlation coefficient. A linear regression analysis was carried out to determine the correlations of femoral/tibial ML and AP dimension. Values with $p < 0.05$ were regarded as significant. The Pearson correlation coefficient r, was categorized as weak, moderate, strong and excellent for $r \leq 0.3$, $0.3 < r \leq 0.7$, $0.7 < r \leq 0.9$, and $0.9 < r$ respectively.

RESULTS

The measurements of proximal tibial morphology are summarised in Table I. For Mongolian Chinese and Han Chinese, both tML and tAP dimensions of the males were significantly larger than those of the females ($p<0.05$) (Table I). For both populations, either of males or of females, significant differences were found in size and shape.

For both populations, tML was positively correlated with the tAP in all conditions, but the tML/tAP aspect ratio was negatively correlated with the tAP in all subject groups (Fig. 2 A1 and A2). Under a given tAP dimension along the regression curves (Fig. 2 A1), Mongolian Chinese males had larger tML than that of Han Chinese males, and both Mongolian and Han Chinese males had a larger tML than those of the females. Furthermore, both Mongolian and Han Chinese males had larger aspect ratios than those of the females under the same tAP values (Fig. 2 A2).

For both populations, the dimensions and aspect ratios of the proximal tibia were compared with four conventional tibial prostheses (Fig. 2 A1 and A2). These prostheses were undersized in tML with the smaller tAP, and overhang in tML with the larger tAP (Fig. 2 A1). Compared to aspect ratios of Mongolian and Han Chinese knees, only one had a similar change of the aspect ratio among four conventional tibial prostheses, but the rate of change was not the same as in both two populations (Fig. 2 A2).

The measurements of distal femoral morphology are summarised in Table I. For Mongolian Chinese and Han Chinese, both fML and fAP dimensions of the males were significantly larger than those of the females ($p < 0.05$) (Table I). For both populations, either of males or of females, significant differences were found in fAP and fML dimensions. Mongolian Chinese females had a larger aspect ratio than Han Chinese females ($p<0.05$).

For both populations, the fML was positively correlated with the fAP in all conditions, but the fML/fAP aspect ratio was negatively correlated with the fAP in all subject groups (Fig.

2 B1 and B2). Under a given fAP dimension along the regression curves, significant differences were found in size and shape between Mongolian Chinese and Han Chinese (Fig. 2 B1). Both Mongolian Chinese males and Han Chinese males had a larger size than those of the females (Fig. 2 B1). Furthermore, significant differences in aspect ratio were found between Mongolian Chinese females and Han Chinese females (Fig. 2 B2).

For both populations, the dimensions and aspect ratios of the femoral were compared with four conventional femoral prostheses (Fig. 2 B1 and B2). Two of femoral prostheses had a larger fML dimension for Mongolian Chinese males and Han Chinese males (Fig. 2 B1). Compared to the aspect ratios of Mongolian and Han Chinese, two of femoral prostheses had a similar change of the aspect ratio for both males, but no designs had a similar change of the aspect ratio for both females (Fig. 2 B2).

Fig. 3 reveals the morphologic relationship between tibia and femur in Mongolian Chinese and Han Chinese knees. The correlation between the tibial mediolateral (tML) and femoral anteroposterior (fAP) dimension is shown in Fig. 3A, and the correlation between the tibial mediolateral (tML) and femoral mediolateral (fML) dimension is shown in Fig. 3B. The fML and fAP were positively correlated with the tML (Mongolian Chinese: $r=0.66$ for fAP; Han Chinese: $r=0.66$ for fAP; Mongolian Chinese: $r=0.97$ for fML; Han Chinese: $r=0.88$ for fML). As the tML dimension increasing, the fML and fAP dimesnions also increased (Fig. 3). Both the Mongolian Chinese and Han Chinese males had larger dimensions than those of females (Fig. 3).

DISCUSSION

The most important finding of the present study was that Mongolian Chinese have a larger size (ML and AP dimensions) and shape (ML/ AP aspect ratio) of proximal tibia and distal femur than that of Han Chinese. Significant differences were found in ML and AP dimensions as well

as ML/AP aspect ratios between both two populations and most conventional knee prostheses. In this study, the measured AP and ML dimensions of Han Chinese were overall close to most previous studies[8,12,15,21,27] (Table II). The differences of dimensions were mainly caused by different measurement methods. The measured fAP dimension of Han Chinese was 10 mm larger than that of Li et al[15] where they did not include the anterior condyle thickness. The tML and tAP measurements from Yang's study[8] were smaller than our data, which may be due to use of the different cut methods.

Several studies have revealed that the Asian knees were generally smaller than Western knees[15,16,28-30] (Table II). Compared with the Brazilian patient knees,[5] the measured fML and fAP dimensions of Han Chinese were smaller, but dimensions of Mongolian Chinese were close to their data. Compared with the reported American knees,[23] the measured fML dimension of Han Chinese in this study was smaller but the measured fAP was larger. In contrast, the measured fML dimension of Mongolian Chinese was close to that of the American data. Therefore, the dimensions of Han Chinese knees were significantly different from the dimensions of Western knees, compared to the dimensions of Mongolian Chinese knees.

Compared with Korean patient knees,[2,9] the measured fML dimension of Han Chinese knees in this study was smaller but the fAP dimension was larger, and the measured tML and tAP dimensions of Han Chinese were larger. Compared with Thailand normal knees,[11] the measured ML and AP dimension of Chinese knees were larger. These results indicated that morphological variations still exist in different ethnicities in Asian population. In present study, Han Chinese and Mongolian Chinese were compared for investigating whether different ethnic groups show different morphological features after TKA simulation. Interestingly, our measurement data revealed the size (AP and ML dimensions of proximal tibia and distal femur) and shape (tibial and femoral aspect ratios) among knees showed significant differences in terms of gender and ethnicity. Therefore, size and shape differences between Han Chinese and

Mongolian Chinese should be considered, especially when choosing suitable prostheses to perform TKA.

Consistent with the previous reported studies,[7,9,12,14,15,21-23,29] our results also demonstrated that both Han Chinese females and Mongolian Chinese females had narrower femoral condyles than those of the males under a given fAP dimension. This may explain the observation that females tend to have more ML overhangs than that of males using current TKA prostheses.[10-12,15,21] Under a given tAP dimension, Han Chinese and Mongolian Chinese females had narrower tibial platform than those of males. The narrower tibial platform implied a potential ML overhang or an AP under coverage if downsizing the prostheses. These may have implications in soft tissue balancing and post-operative tibia positioning. Therefore, the design of the femoral and tibial prostheses should consider the gender variations.

In term of mismatch between the Chinese knees and the available four TKA prostheses, the measured femoral data had a larger fML with all range of fAP, which was more evident in females. For the aspect ratio (fML/fAP) and fAP dimension, only one of prostheses showed a decreasing femoral aspect ratio as the fAP dimension increased, but the rate of change was not the same as that in the Han Chinese and Mongolian Chinese. The other prostheses showed no change in the femoral aspect ratio with the increasing fAP dimension. Similarly, our tibial data showed a decreasing aspect ratio (tML/tAP) as the tAP dimension increased, similar to observation in other studies.[15,25] However, most current prostheses had a constant aspect ratio. We found that tML dimension was undersized with the smaller tAP dimension, and overhang with the larger tAP dimension. This was more evident in Han Chinese and Mongolian Chinese male knees. Therefore, the suitable knee prostheses should be provided according to the ethnicity and gender differences.

The morphologic relationship between the tibia and femur in Han Chinese and Mongolian Chinese was investigated in this study. We found that the tML was positive

correlated with the fML and fAP (Mongolian Chinese: r=0.97 for fML; Han Chinese: r=0.88 for fML; Mongolian Chinese: r=0.66 for fAP; Han Chinese: r=0.66 for fAP), the trend are similar to the reported by Cheng et al.[12] The measured results suggested it may be important to consider the tibia and femur as a whole for the prostheses design. Therefore, the tML and fAP should be considered as the important factors to design proper prostheses for Han Chinese and Mongolian Chinese.

Some limitations of this study should be discussed. First, a total of only 74 normal knees were analysed, and therefore these results only provided general guidelines for gender-specific and ethnicity-specific knee prostheses. A small number of samples were used, and more samples should be investigated in future studies. Second, the current study only evaluated the knees of healthy Han Chinese and Mongolian Chinese without considering the patients with inflammatory arthritis or rheumatoid, which limits our conclusions to patients with the knee degeneration. At present study, only four types of knee prostheses were evaluated for mismatch comparison, and other types of knee prostheses should be considered in the next step. In addition, further investigation is needed to evaluate any clinical impact of implant designs based on these ethnic differences.

In conclusion, the results of the present study indicate that Mongolian Chinese have a larger size and shape of proximal tibia and distal femur than that of Han Chinese. Significant differences were found in ML and AP dimensions as well as ML/AP aspect ratios between both two populations and most conventional knee prostheses, the variations in ethnicity and gender should be considered for the development of anatomic knee prostheses.

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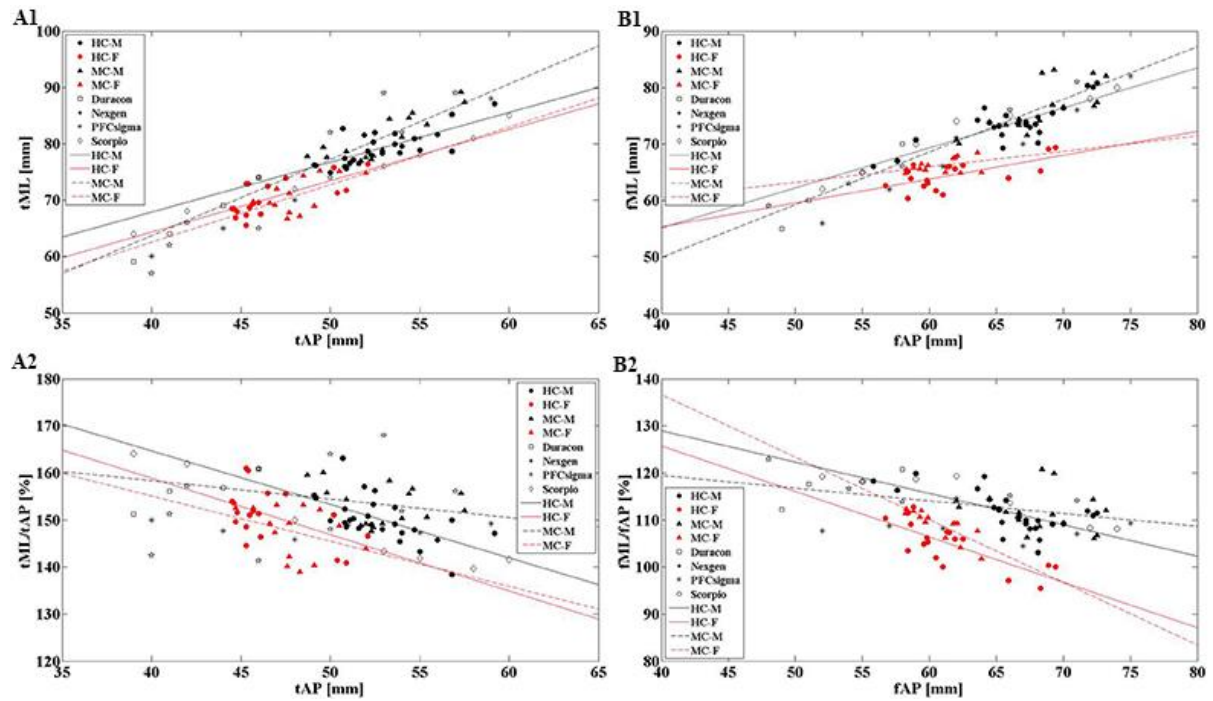
Fig. 1 Cuts and measurements of the proximal tibia and distal femur
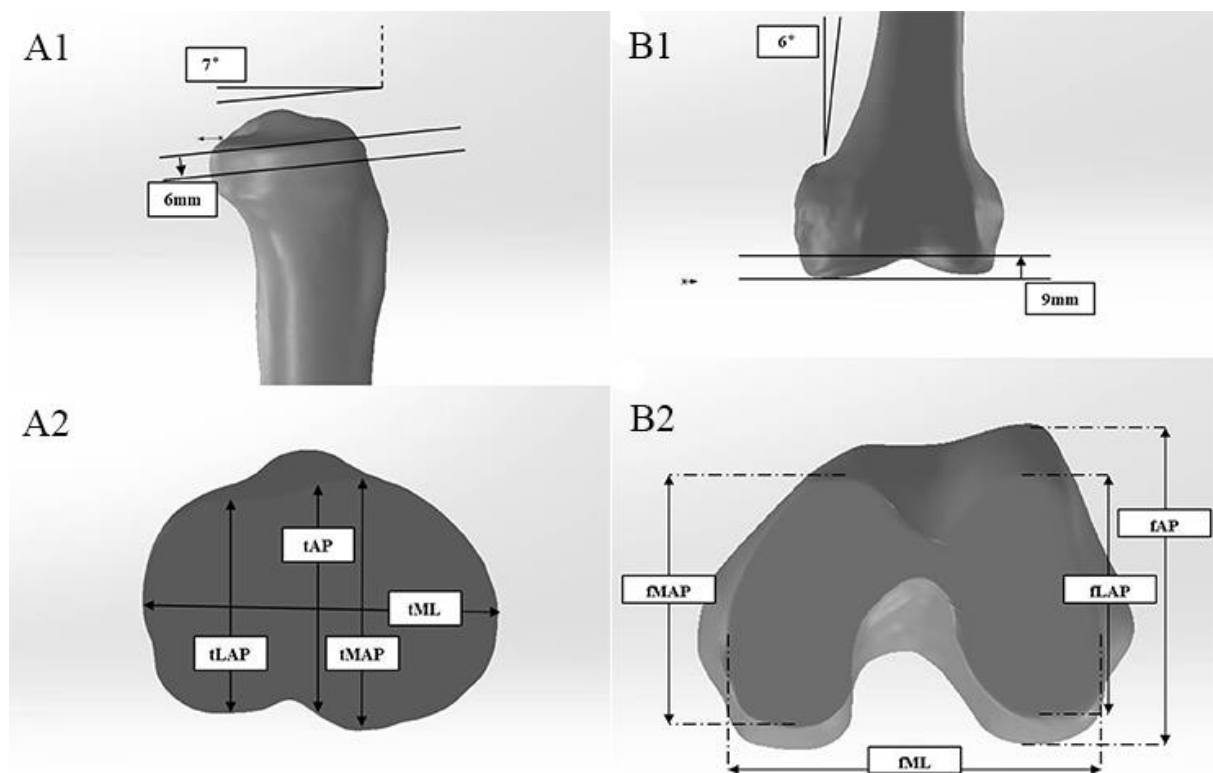
Fig. 2 Ethnicity and gender effects on resected proximal tibia and distal femur of Mongolian Chinese males (MC-M) and females (MC-F), Han Chinese males (HC-M) and females (HC-F). tML and tAP dimensions as well as tML/tAP aspect ratio in Mongolian and Han Chinese knees compared with tibial and femoral prostheses.
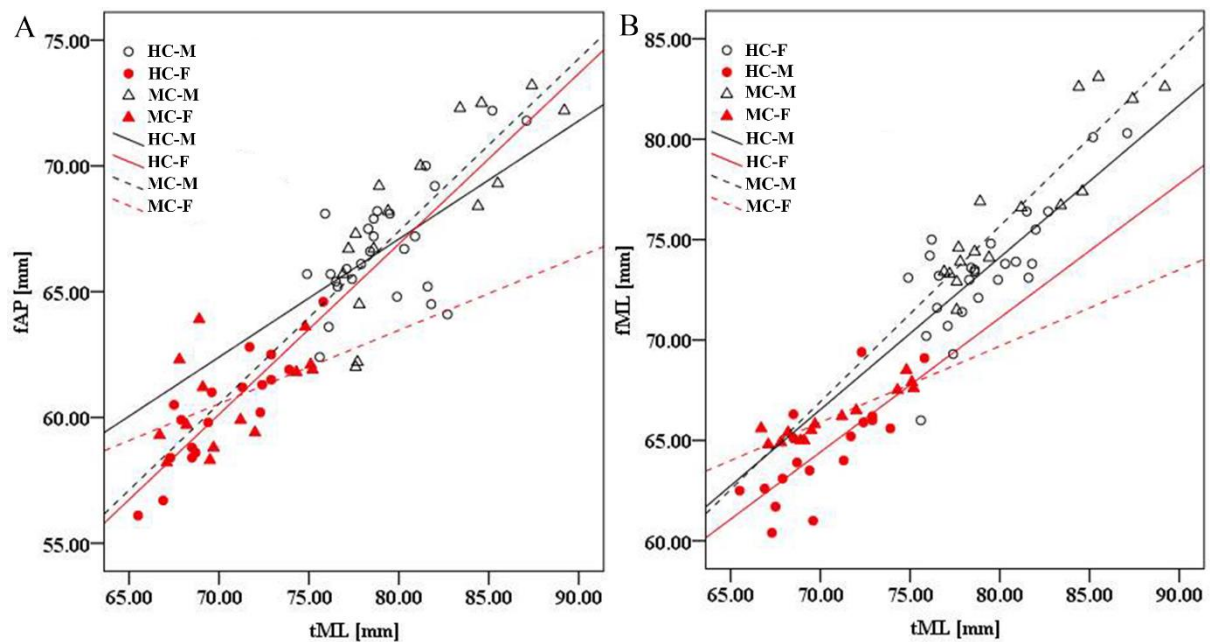
Fig. 3 The morphological relationship between the tibia and femur in Mongolian Chinese males (MC-M) and females (MC-F), Han Chinese males (HC-M) and females (HC-F).

Table I. Average values of the tibia and femur morphology measurement (mm)

Parameters	Mongolian Chinese		Han Chinese	
	Male	Female	Male	Female
Tibial mediolateral(tML)	81.09 ± 4.06	70.69 ± 3.08	78.52 ± 4.30	70.39 ± 3.15
Tibial anteroposterior(tAP)	52.93 ± 2.56	47.98 ± 1.89	52.37 ± 3.13	46.22 ± 3.07
Tibial medial anteroposterior tMAP	54.26 ± 2.35	48.06 ± 1.68	53.69 ± 3.39	47.69 ± 2.66
Tibial lateral anteroposterior tLAP	48.89 ± 3.61	45.42 ± 3.39	49.66 ± 3.88	44.66 ± 2.59
Aspect ratio (tML/tAP %)	153.26 ± 4.22	147.39 ± 5.31	150.06 ± 4.86	152.81 ± 10.98
Femoral mediolateral(fML)	76.21 ± 4.35	65.56 ± 2.26	73.64 ± 3.52	64.53 ± 2.49
Femoral medial anteroposterior(fMAP)	53.93 ± 2.18	49.35 ± 1.98	52.97 ± 1.81	50.18 ± 1.83
Femoral lateral anteroposterior(fLAP)	53.39 ± 2.15	48.71 ± 2.02	52.48 ± 1.80	49.73 ± 1.85
Femoral anteroposterior(fAP)	68.15 ± 3.48	60.74 ± 1.90	66.14 ± 4.01	61.74 ± 3.84
Aspect ratio (fML/fAP %)	111.87 ± 4.28	107.97 ± 3.49	111.50 ± 4.14	104.73 ± 4.84

Table II. Comparison of the morphological data with those reported in literature

Authors	Population	fML (mm)	fAP (mm)	tML (mm)	tAP (mm)	Prostheses (compared)
Loures et al, 2016	Brazilian	77.7±4.9(M) 67.8±4.0(F)	70.3±4.7(M) 61.5±4.9(F)	79.8±5.8(M) 69.6±4.3(F)	53.9±6.1(M) 46.0±4.0(F)	More than a quarter of patients unsatisfied
Miyatake et al, 2016	Japanese			76.4±3.2(M) 68.3±2.9(F)		Genesis II and Persona better than NexGen
Erkocak et al, 2015	Turkish			77.1±5.1(M) 68.7±3.6(F)	47.6±3.8(M) 40.9±3.1(F)	mismatched
Chung et al, 2015	Korean	76.1±4.0(M) 67.9±3.3(F)	67.2±3.9(M) 61.1±3.2(F)			mismatched
Li et al, 2014	Caucasian	74.6±3.9(M) 65.4±1.4(F)	59.6±3.2(M) 55.4±2.8(F)	79.4±4.3(M) 70.2±2.7(F)	49.5±2.9(M) 45.2±2.3(F)	
Yue et al, 2014	Chinese					morphological or Gender specific Prostheses (better)
Yang et al, 2014	Chinese	79.0±5.0(M) 71.2±4.3(F)	66.8±4.0(M) 61.3±3.3(F)			
Yang et al, 2014	Chinese			77.3±4.7(M) 71.1±3.7(F)	48.5±4.0(M) 44.7±3.5(F)	mismatched
Li et al, 2014	Chinese	72.7±3.8(M) 64.4±2.6(F)	56.5±2.5(M) 52.8±2.6(F)	77.4±3.3(M) 69.1±2.8(F)	49.6±2.4(M) 44.2±2.3(F)	
Lim et al, 2013	Korean	81.5±5.7(M) 76.7±3.71(F)	59.0±4.01(M) 58.4±3.10(F)	80.6±6.31(M) 70.0±3.45(F)		
Chaichankul et al, 2011	Thai	70.15±3.87(M) 59.91±3.75(F)		74.44±3.44(M) 64.95±3.45(F)	50.15±3.09(M) 43.23±2.57(F)	mismatched
Cheng et al, 2009	Chinese	74.4±2.9(M) 66.8±3.1(F)	66.6*±2.4(M) 61.0±2.7(F)	76.4±2.8(M) 68.8±4.6(F)	51.3±2.0(M) 45.7±1.9(F)	mismatched
Lonner et al, 2008	American	76.92 (M) 67.49(F)	62.27(M) 56.32(F)			
Kwak et al, 2007	Korean			76.1±4.0(M) 67.64±3.12(F)	48.2±3.3(M) 43.2±2.3(F)	mismatched
Uehara et al, 2002	Janpanese			77.9±4.1(M) 69.5±3.4(F)	54.1±3.0(M) 49.2±2.9(F)	mismatched
Present study	Mongolian Chinese	76.21±4.35(M) 65.56±2.26(F)	68.15±3.48(M) 60.74±1.90(F)	81.09±4.06(M) 70.69±3.08F)	52.93±2.56(M) 47.98±1.89(F)	mismatched
Present study	Han Chinese	73.64±3.52(M) 64.53±2.49(F)	66.14±4.01(M) 61.74±3.84(F)	78.52±4.30(M) 70.39±3.15F)	52.37±3.13(M) 46.22±3.07(F)	mismatched