Title: Knee morphometry for the Arabian population with a comparison to designs of 6 different total knee implants.

Authors:

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Abstract.

Introduction**:** The knee joint morphology varies from one ethnic group to another. Other factors contribute to this variation such as gender and the morphotype of the patients. To the authors' knowledge, there are no studies in the literature regarding anthropometric parameters of the Arabian knee as it relates to knee implants.

Purpose: The objective of this study was to measure the dimensions of the osteoarthritic knees of Arabian patients and to compare these measurements with the dimensions of six knee implants.

Subjects and Methods**:** CT scans were used to collect morphologic data from the distal part of the femur and the proximal part of the tibia from 124 osteoarthritic knees**.** Anteriorposterior and mediolateral measurements were obtained from three dimensional resected bony surface. These measurements were compared with similar dimension for six different types of knee implants.

Results**:** We found that Arabian knee were generally smaller than Caucasian knee, Arabian females were found to have smaller measurement values when compared with male. Most of proximal tibial plateau and femur condyles were asymmetrical

Conclusion**:** Our data suggests mismatch between osteoarthritic Arabian knee and implant designs. This result suggest that to consider ethnic difference when designing Total knee implants.

Key words: Arabian knee, Morphometry, CT, Total knee arthroplasty. Patient Specific Instrument.

Conflict of interest statement

No conflict of interest related to this study

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Introduction

The knee joint morphology varies from one ethnic group to another. Other factors contribute to this variation such as gender and the morphotype of the patients [1]. Understanding the morphology and functional anatomy of the knee joint of each ethnic group has become essential for both orthopaedic surgeons and knee implant manufacturers. It helps not only in treatment planning but also in addressing the general type of deformity that is common in a specific ethnic group [2,3,4]. Different imaging modalities can be used to assess anthropometric measurements of the patients. CT scan or MRI is commonly used in preoperative measurement of knee dimensions. Moreover, intraoperative measurement of resected bony surface during total knee arthroplasty (TKA) has also been used [2,3,4,6,7].

Recently, there is an increasing number of published data on morphometric measurements of the knee following the introduction of patient specific instruments that require preoperative CT or MRI imaging [22]. The availability of reconstructed data of arthritic knees encouraged many researchers to analyze large number of data either in 2-D or 3-D fashion.

However, the majority of studies done on knee morphometry have been focusing on Caucasian population. Some recent research work has shed light on the Asian population. Many studies have revealed anthropometric differences for the Asian population when compared to Caucasian [2,3,4]. Current TKA implants are designed according to the anthropometric data of Caucasian knees, which has been suspected as the cause of the component mismatch in other ethnic groups [2].

Arabia population has a higher incidence of knee osteoarthritis (OA) up to 60 % for patients aged 66 and above [18]. This is possibly due to the social habits of squatting and sitting with cross legs. They usually present late with varus and flexion deformity. They relatively have more sedentary life style and they demand higher degree of knee flexion for their TKR.

To the authors' knowledge, there are no studies in the literature regarding anthropometric parameters of the Arabian knee as it relates to knee implants. The aim of this study was to measure the dimensions of the osteoarthritic knees of Arabian patients and to compare these measurements with the dimensions of seven knee implants.

Materials and methods:

A total of 124 knee CT scans of consecutive patients who underwent TKA with open-platform PSI technique were included in this study. Ethical committee approval was obtained from our instituation prior to using CT scan and PSI technique. All patients had preoperative CT scan of the knee and underwent TKA. The PSI preoperative planning for all cases was approved and the TKR surgery was performed by the first author (MAH). There were 24 male knees and 100 female knees. The average age of the patients at time of CT scaning was 59.9 years(49-71). The demographic distribution of the patients spans 11 Arab countries (Egypt, Yemen, Sudan, Libya, Saudi Arabia, Syria, Iraq, Somalia, Djibouti, Palestine, Jordan)

The CT scan protocol and the PSI technique was previously reported[20]. A 160 slices CT with 1mm slice thickness was performed for the knee joints. All patients were scanned in the supine position with the knee extended and patella facing forward. The mechanical axis of the joint was defined using scanogram. The measurements were performed using Solidworks software (Dassault Systemes, ver.2014, USA)

The proximal tibia measurements were performed at the level of tibial resection, 6-8 mm below the lateral tibial plateau and perpendicular to the mechanical axis of tibia with a 7° posterior slope [3], as actually planned using PSI to simulate intraoperative bone cutting of the proximal tibia.

At the resected surface of proximal tibia, the mediolateral dimension of tibia (tML) was taken as the maximum width of mediolateral length at the resected tibial surface. This (tML) dimension was adjusted to be parallel to the epicondylar axis of the femur, which was defined as line connecting the lateral epicondylar prominence and the medial sulcus of the medial epicondyle [4]. The middle anteroposterior dimension of tibia (tAP) was taken as the line drawn perpendicular to and at the mid-point of the tML line. The lateral anteroposterior (tLAP) and the medial anteroposterior (tMAP) dimensions were defined as the longest lines drawn parallel to the tAP line, perpendicular to the tML line and reaching most posterior point of the lateral and the medial condyles of tibia respectively (Figure 1). The distance from the lateral anteroposterior (tLAP) and the medial anteroposterior (tMAP) dimensions to the middle anteroposterior line of tibia (tAP) were defined as the lateral to central distance (CL), and the medial to central distance (CM) respectively [6]. The tibia aspect ratio (tAR) calculated as the tML dimension divided by the middle anteroposterior dimension of tibia (tAP) dimension ×100%? [7].

The distal femur measurements were done at the level of femur resection, this femur resection was performed at 9mm above the most inferior point of the medial condyle with

6° valgus, so as to simulate the optimal intraoperative bone cutting for the distal femur. First the femur epicondylar axis was set, by drawn a line connecting the lateral epicondylar prominence and the medial sulcus of the medial epicondyle [4]. The femoral anteroposterior (fAP) measurement was taken as the maximum width of the lateral condyle in the AP axis [5]. At the resected surface of distal femur, the mediolateral dimension of femur (fML) was taken as the maximum width of mediolateral length . The femoral medial anteroposterior (fMAP) and femoral lateral anteroposterior (fLAP) measurement were taken as the widest dimension of the medial and lateral condyles and perpendicular to the tML line (Figure 2). The distance from the lateral anteroposterior (fLAP) and the medial anteroposterior (fMAP) dimensions to the central anteroposterior line of femur were defined as the lateral to central distance (CL), and the medial to central distance (CM) respectively. The femur aspect ratio (fAR) calculated as the fML dimension divided by the fAP dimension ×100% [5,7].

Six implant types, namely, NexGen (Zimmer, USA), PFC-Sigma (Depuy, J & J, USA), Triathlon (Stryker, USA), Vanguard (Biomet), Profix(Smith & Nephew) and SLK EVO (Implant International, UK) were studied to determine their ML, AP lengths and aspect ratios.

Statistical analysis was performed using IBM SPSS statistics 22. Data were summarized as the mean and standard deviation. The Student t-test, the Paired t-test and the Pearson's correlation coefficient were calculated. Comparisons were regarded as statistically significant when P value less than 0.05.

Results:

This study included 124 knees in (92) patients. Female to male ratio was 4:1 (100 female and 24 male). The mean age was 49.9 years (range: 49-71).

In resected tibial bony surface, we found that the average tibial mediolateral (tML) and tibial anteroposterior (tAP) measurement for Arabian knees were 74.36±6 mm and 48.94±4.57 mm, respectively. There are larger values for tML and tAP for males when compared with females ($p<0.00001$) (Table 1).

To evaluate the symmetry between the medial and lateral tibial plateau tMAP and tLAP were measured, we found that the average tibial medial anteroposterior (tMAP) and lateral anteroposterior (tLAP) were 52.17±4.61 and 46.78±5.18 mm, respectively. There was significant difference between the two dimensions (tMAP-tLAP), the average value for the difference (tMLD) for males and females were 2.93±5.29 mm and 5.98±4.23 mm, respectively. According to these results, medial tibial plateau is larger than lateral tibial plateau in the anteroposterior direction. The distance from tAP to tMAP and tLAP(CM and CL dimensions) were measured for further evaluation of the asymmetry between the medial and lateral tibial plateau, it was confirmed that tMAP was closer to the midline than tLAP by average of 2.86±5.11 mm (t-Score = 5.81, p-value < 0.00001)

To identify the accurate size of the tibial component for the Arabian population, we compared the ML and AP dimensions of the resected tibial bony surface with similar measurements of six tibial implants (Figure 3). To assess the geometry of resected bony surface, the aspect ratio was measured, which was the ratio of ML/AP. The average aspect ratio was 152.62±12.66 (Table1). We compared the aspect ratio with AP dimension of proximal tibia. The aspect ratio of the proximal tibia showed a progressive decline with the increasing AP dimension?. The aspect ratio and AP dimension of proximal tibia were compared with corresponding values of six tibial implants commercially available. Only one of prosthesis showed a declining change with the increasing AP (Figure 4)?.

The average femur mediolateral (fML) and femur anteroposterior (fAP) measurement for Arabian knees were 72.04±6.6 and 68.1±7.75, respectively. There are larger values for fML and fAP for males when compared with females (p<0.00001) (Table 2).

To evaluate the asymmetry between the medial and lateral femur condyles, fMAP and fLAP were measured, we found that the average femur medial anteroposterior (fMAP) and lateral anteroposterior (fLAP) were 51.82± 6.06 and 49.45±6.24 mm, respectively. The distance from the center to MAP and LAP (CM and CL dimensions) were measured for further evaluation of the asymmetry between the medial and lateral femur condyles, it was confirmed that MAP was nearer to center than LAP by average of 4.01±5.36mm(t-Score = 9.31, p< 0.00001).

To assess whether the femoral component of modern TKA were suitable for the Arabian knee or not, the aspect ratio of the femur was calculated. The average aspect ratio was 106.37±14.34 (Table 2). We compared the aspect ratio with AP dimension of resected bony surface of distal femur. We then compared aspect ratio and fAP with comparative measurements of six femoral components of commercially available knee prostheses.

To identify the morphological matching between resected bony surface of proximal tibia and distal femur in individual Arabian knee, we compared the tibial mediolateral (tML) to femoral mediolateral (fML) and anteroposterior (fAP) dimensions (Fig.6).A strong correlation was found between the fML and fAP with tML(Pearson correlation =0.391, p <0.00001 and pearson correlation=0.3248, p<0.00001 respectively).

Discussion:

In total knee arthroplasty, accurate shape matching between the prosthesis and knee resected bony surface is detrimental factor for long term good results[18]. Overhang of prosthesis may lead to soft tissue impingment and irritation, in contrast undercoverage of resected surface may lead to subsidence and instability.

To the authors' knowledge, no previous study has been published on Arabian population with view of knee morphometry. The aim of this study was to measure the dimensions of the osteoarthritic knees of Arabian patients and to compare these measurements with the dimensions of six knee implants.

This study has limitations. The number of knees is only 124 and predominantly females. However, this is a real life circumstances representing the average distribution of consecutive TKA between males and females. Although there are patients from 11 Arab countries, the majority of patients were from Egypt.

In the present study, 3D CT scan was used to evaluate the morphology of the Arabian knee, with patient specific instruments (PSI) technique and maintaining proper level of cuts in coronal and sagittal planes similar to operative scenario . Lee et al.(2006) studied knee morphologic data measurement by CT scan, and concluded that the measurements by CT scan have similar agreement with intraoperative measurements[19].

The recent introduction of PSI and the need for preoperative imaging supplied a large number of 3-D data of arthritic knees. Some of these data are based on CT (reference Hafez CORR 2006 and others) and others are based on MRI (reference Thienpont 2013, Howell). CT scan has several advantages as it is cheaper, faster and has fewer contraindications as compared to MRI scan. With regards to planning and measurements, CT has a more important advantage of easier segmentation that could be done automatically by the software. MRI has the advantages of no radiation risk and better visualization of cartilage. For morphometric measurements, we believe CT scan is better than MRI because the measurements are based on bone and not cartilage, this in addition to other advantages for CT scan as listed above

No similar studies on Arabia population were found in literature but there are similar studies on other populations. The results of our study regarding the morphometry of the proximal tibia (in mm), the parameters tML and tAP were significantly smaller in female than male this mean tibial resected surface was larger in male. We found our results generally less than Caucasian population, Many investigators have documended that Asian knees are smaller than Caucasian knees[]. In contract when compared our data to different Asian population (Table 3) we found that the Arabian knee morphology larger than Asian knee.

In the present study, we revealed that tibial medial AP was significantly longer than tibial lateral AP, in addition to that distance from tLAP to center is longer that tMAP to center, this concluded that there was asymmetry between medial and lateral tibial plateau []. These results may indicate that the need for asymmetric tibial prosthesis to maximize resected surface coverage for tibia. In contrast to investigators that advocated symmetric prosthesis[].

When the morphometric measurements of Arabian knees were compared to 6 current knee implants, it was found that the aspect ratio value decreased when tAP dimension increased, similar to other reports[], but the majority of knee implants showed constant aspect ratio with the increase of AP dimension(figure 4). So a constant implant aspect ratio indicates ther is constant shape for knee implant, this lead to oversizing or undersizing with the changing of AP dimension.

The results of our study regarding the morphometry of the distal femur (in mm) was compared to the results of other studies on different populations []. Table 4 is showing that distal femur of Arabian knees was different from other reports[].

With regards to the differences between morphometric measurements of males and females, this study showed significant higher parameters for males when comparedto female, this similar to observation of different studies[].

The distal femur of the Arabian population, our results results showed anatomic differences between Asian and Caucasian, and female and male

Mensch et al.(1975), found that the medial condyle width was larger than the lateral condyle width by 3mm. our results confirmed that the medial condyle was larger than the lateral condyle by an average of 2.37 mm, these results may imply that asymmetric femoral component may required for Arabian knee.

Regarding morphologic relation between resected bny surface of the proximal tibia and the distal femur for Arabian knee, we found strong correlation between tibial mediolateral with femoral AP and mediolateral(r= p) similar to reports of Cheng et al[]. So prosthetic design preferably to consider tibia and femur together.

New featuresfor our study:

Methods:

PSI planning, maintaining sagittal, coronal alignment.

Intraoperative confirmation specialy for the femur.

Excluding osteophyte

Arthritic knee old age

All cases had TKR

Results

CM-CL For femur

Conclusion

Morphometric measurements of Arabian knees showed some differences in comparison to Caucasian and Far East. For proximal tibia, …….

For distal femur………

There was a mismatch between the surgical anatomy of the Arabian knee in comparison to the currently available TKA implants. Further studies are needed in order to overcome some of the limitations in our study particularly, the ratio between males and females and the inclusion of all Arab countries.

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Legends

Figure 1: Tibial resection and measurements taken in the 3D image of the knees. The proximal tibia resected 6 mm below the lateral tibial plateau with a 7° posterior slope. The tML dimension was taken as the longest mediolateral length, parallel to the femoral epicondylar axis, at the proximal tibial resected surface. The tAP line was taken as perpendicular to and passing through the midpoint of the tML. The tMAP and the tLAP were taken passing through the posterior most points of the medial and lateral tibial condyles and parallel to the tAP. Also CM and CL distance were determined.

Figure 2: Femoral resection and measurements were taken in the 3D image of the knee. The distal femur was cut 9 mm above the lowest point of the medial condyle with 6° valgus. The arrows show the prominences of the epicondyles, ML axis was taken as the epicondyle axis. The fML was measured as the width of the surface at the epicondylar axis. The fMAP and fLAP were taken as the widest dimension of the medial and lateral condyles and perpendicular to the tML line. Also CM and CL were determined

Figure 3: The proximal tibial mediolateral (tML) versus anteroposterior (tAP) dimensions for 124 Arabian knees were compared with same value of six tibial prostheses.

Figure 4: The tibial aspect ratio versus the anterior-posterior (tAP) measurements (mm) for 124 Arabian knees compared with six tibial prostheses.

Figure 5: The Femur mediolateral (fML) versus anteroposterior (fAP) dimensions for 124 Arabian knees were compared with similar values of six femur prostheses.

Figure 6: The femur aspect ratio versus the anterior-posterior (fAP) measurements (mm) for 124 Arabian knees compared with six femur prostheses.

Figure 7: The morphological relationship between the tibia and femur for Arabian knees.The relationship between tibial mediolateral (tML) and femoral mediolateral (fML) dimension.

Figure 8: The morphological relationship between the tibia and femur for Arabian knees. The relationship between tibial mediolateral (tML) and femoral anteroposterior (fAP) Dimension.

Figure 9: Proximal tibia dimensions for Arabian in comparison with different population.

Figure 10: Distal femur dimensions for Arabian in comparison with different population.