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Natural distribution of the femoral mechanical–anatomical angle in an osteoarthritic population and its relevance to total knee arthroplasty

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A B S T R A C T

A common surgical goal in TKA is to restore neutral alignment of the lower limb by making bone cuts perpendicular to the mechanical axes of the femur and tibia. Standard practice for many surgeons is to use the same distal femoral valgus resection angle for all patients, assuming little or no variation in the femoral mechanical–anatomical (FMA) angle between different patients' knees. This study analysed 174 pre-operative hip–knee–ankle radiographs of osteoarthritic knees (157 patients, 87 female and 70 male, mean age 70 years and mean BMI 31.8). Measurements of mechanical femorotibial (MFT) and FMA angles were made. The mean FMA angle was 5.7° (SD 1.2°, range 2° to 9°). There was a statistically significant difference between the FMA angle for males and females with males tending to have larger FMA angles ($p<0.001$). There was a statistically significant correlation between MFT and FMA angle ($r=-0.499$) with varus knees tending to have larger FMA angles ($p<0.001$). These results indicate a wide distribution of FMA angle in an osteoarthritic population. In terms of achieving appropriate coronal alignment in TKA the use of a fixed valgus resection angle is not suitable for all patients and it may be preferable to adjust the distal femoral cut according to individual FMA angles. However if this angle is not available the cut may be adjusted according to pre-operative coronal alignment, using 6° for neutral/mild varus, >6° for more severe varus and <6° for valgus knees.

1. Introduction

Osteoarthritis of the knee is a disease that occurs in both genders and is usually associated with increasing age. The main symptoms are pain on movement and lower limb deformity which lead to loss of function. This is given to be because the knee is involved in weight-bearing, has a high range of motion and its stability comes from soft tissue structures rather than bony anatomy [1]. Total knee arthroplasty (TKA) surgery has become a successful operation in terms of relief of symptoms of osteoarthritis, such as pain and reduced mobility. While the survival rates of knee implants are generally good, the most common reasons for failure include aseptic loosening, malalignment, instability and infection. The alignment of TKA implants is important as it is known to affect wear, instability and loosening [2].

A common surgical goal in TKA is to restore neutral alignment of the lower limb [14] which can be achieved by making bone cuts perpendicular to the mechanical axes of the femur and tibia. With traditional instrumentation this goal is achieved by using an intramedullary guide and setting the distal femoral resection angle manually before the cut is made [3,4]. For this to be successful the selected resection angle must be the same as the angle between the mechanical and anatomical axes of the femur — the femoral mechanical–anatomical (FMA) angle (Fig. 1). Failure to achieve a perpendicular cut may lead to malalignment which in turn can cause knee pain, instability and, in some severe cases, premature implant failure [2,5].

When cutting the distal femur with an intramedullary guide, standard practice for most surgeons is to use the same distal femoral valgus resection angle for all patients, typically 6°. This practice assumes little or no variation in the FMA angle between different patients' knees. Recent studies have contradicting conclusions regarding the suitability of this practice. Although Kharwadkar et al. showed acceptable results, Bardakos et al. showed that the mechanical axis cannot be restored in TKA using a fixed valgus resection angle [4,6]. Elkus et al. recommend using a 3° valgus cut for TKR patients with valgus deformities in order to avoid under-correction of the valgus deformity, but provides little more explanation [7].

Literature on the FMA angle is mainly focused on the healthy population. The overall mean FMA angle for healthy adults of Chinese origin has been shown to be 5.1°, SD 0.9°, with a range of 2.6°–7.4° [8]. Another study of the same ethnic group found that males had a mean FMA angle of 5.6°, SD 0.8° with females being 5.7°, SD 1.0° [9]. A strong correlation between coronal alignment and FMA angle ($r=-0.58$, $p<0.001$) has also been identified in this population [8]. However this was for "normal" knees where the mechanical femorotibial (MFT)

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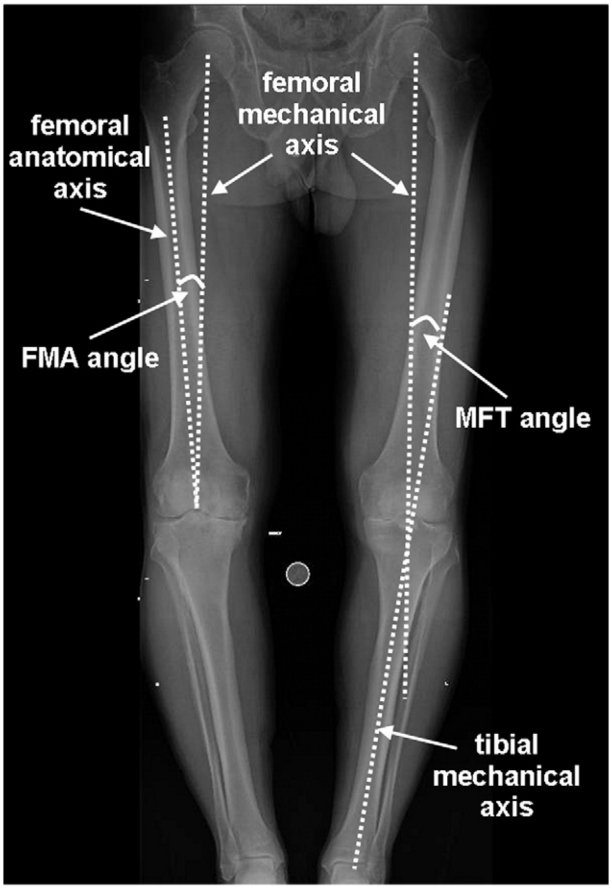

Fig. 1. Identification of hip, knee and ankle centres, construction of axes (mechanical femoral axis, mechanical tibial axis and anatomic femoral axis) and angles (FMA angle and MFT angle).

angle only varied from 5.4° varus to 5.5° valgus. For a western population of normal healthy adults the mean FMA angle has been measured as 5.8°, SD 1.9° but again the range of coronal alignment was small being a mean of 1.2° varus, SD 2.2° [1]. All these data refer only to healthy adults and do not cover the range of coronal deformity seen in a TKA patient population. Extrapolation of results could therefore lead to error. Desme et al. did look at the FMA angle in patients with osteoarthritis of the knee and found that varus knees had an FMA angle of 6.3° (SD 6.3°) but for valgus knees this was 4.7° (SD 1.4°) [10]. However their treatment of varus and valgus groups separately does not give a clear picture of the overall distribution in osteoarthritic patients.

The aim of this study was to assess the distribution of the FMA and MFT angles in an osteoarthritic population. The hypothesis was that within this group the FMA angle would show a wide natural distribution and would be correlated to the pre-operative coronal limb alignment as measured by the MFT angle.

2. Patients and methods

The local research ethics committee was approached and they determined that ethical approval was not required for this study.

All patients with osteoarthritis presenting at our institution for TKA surgery under the care of the senior author (MS) between January 2007 and October 2007 were included in the study. All patients had pre-operative hip–knee–ankle radiographs (long-leg films). The method of taking the long-leg radiographs was an antero-posterior view of the knee joint including hip and ankle. Patient assumed a bi-pedal stance 180 cm in front of the X-ray source tube (GE Definium 8000). The knee was rotated internally by 5° to bring the intercondylar line parallel to the plane of the detector. These radiographs were then stored in the Kodak PACS (Picture Archiving Communications System), which allowed measurement of both the FMA and MFT angles.

The initial step in the generation of the FMA and MFT angles was the definition of the hip, knee and ankle centres. The hip centre was identified using a Mose circle [11]. The centre of the knee joint was identified as the apex of the intercondylar notch. The centre of the talus determined the centre of the ankle joint. The femoral mechanical axis was then defined as a line joining the centre of the hip and the centre of the knee, with the tibial mechanical axis being a line joining the centre of the knee and the centre of the ankle. The femoral anatomic axis was defined as a straight line along the mid-diaphyseal path of the femur. The FMA angle was defined as the angle between the femoral anatomic axis and the femoral mechanical axis. The MFT angle was defined as the angle between the femoral mechanical axis and tibial mechanical axis (Fig. 1). In order to determine errors in measurement of these angles on the radiographs, intra- and inter-observer variabilities were also assessed. Two observers measured 48 randomly selected radiographs on two separate occasions with no reference to either their own or the other's measurements.

Statistical analysis was completed using Excel (Microsoft Corp., Redmond, WA, USA) and SPSS 17.0 (SPSS Inc., Chicago, IL, USA). Intra- and inter-observer variability was assessed using the intra-class correlation coefficient. Cluster analysis was completed using K-Means. Group comparisons were made using Kruskal–Wallis or Mann–Whitney tests as appropriate. Pearson's correlation was used.

3. Results

One hundred and seventy four pre-operative radiographs of 157 patients undergoing TKA were included in the study. There were 87 women and 70 men with a mean age of 70 years (range 44–89 years). Mean BMI was 31.8 (range 19.8–50.2).

Inter-observer comparison showed an intra-class correlation coefficient (ICC) of 0.86 for the FMA angle and 0.99 for the MFT angle. In 47 knee radiographs, intra- and inter-observer measurements of the FMA angle varied within 1°. Only one case had an inter-observer variation of 2°. Intra- and inter-observer variations of the MFT angle were within 1° for 43 cases and within 2° for a further four cases. Only one case with significant varus alignment and subluxation of the knee showed an inter-observer variation of 3°.

The mean FMA angle for the study group was 5.7° (SD 1.2°) (range 2° to 9°) (Fig. 2). The coronal plane deformity (MFT angle) ranged from 23° varus to 16° valgus. Twenty two percent of the study group had a valgus MFT angle, 76% had a varus and 2% had neutral alignment (Fig. 3).

The distribution of FMA angle for males and females indicated that males tended to higher FMA angles and females tended to lower FMA angles (Fig. 4). The Mann Whitney test showed a statistically significant difference between the FMA angle for males and females, $p<0.001$.

Variation in the FMA angle followed a normal distribution. Visual analysis suggested that the FMA angles measured in the study fell into one of three groups based on coronal alignment — severe varus, moderate varus to mild valgus and

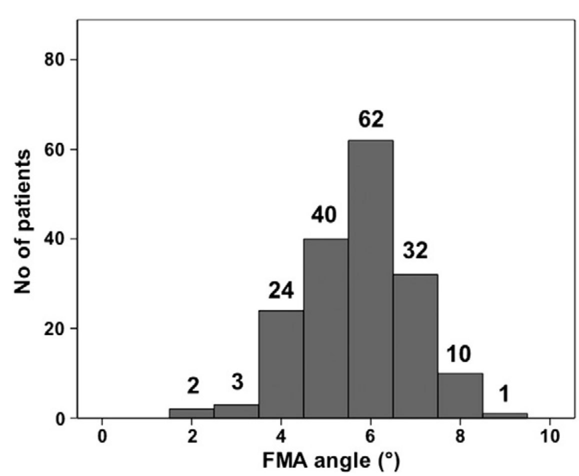

Fig. 2. Histogram showing distribution of FMA angle for study cohort.

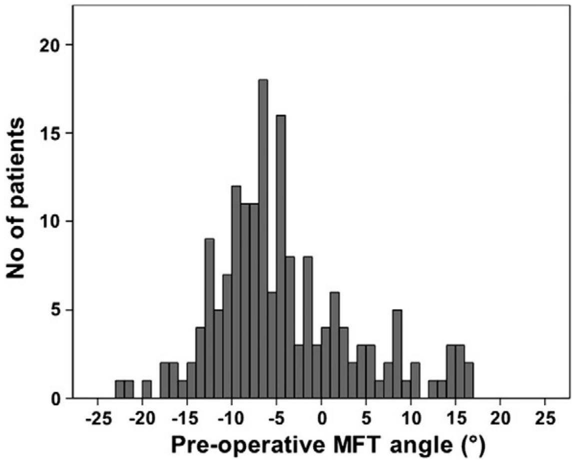

Fig. 3. Histogram showing distribution of pre-operative MFT angle for study cohort.

Table 1
Numbers of patients in each group with FMA angle of less than the overall median angle, having the overall median angle or greater than the overall median angle.

Group	MFT angle boundaries	n	FMA angle median [range]	No. patients with given FMA angle		
				<6°	6°	>6°
Severe varus	9° or more varus	58	7° [4°to 9°]	12 (21%)	16 (28%)	30 (52%)
Moderate varus to mild valgus	8° varus to 1° valgus	83	6° [3°to 8°]	32 (39%)	39 (47%)	12 (14%)
Moderate to severe valgus	2° or more valgus	33	5° [2° to 7°]	25 (76%)	7 (21%)	1 (3%)

moderate to severe valgus. Cluster analysis was performed to identify the boundaries for each group (Table 1). The median FMA angle was higher for the severe varus group and lower for moderate to severe valgus when compared to the moderate varus/mild valgus group (Table 1). The Kruskal Wallis test showed that these were statistically significant different, $p<0.001$. The proportion of patients having an FMA angle greater than or less than 6° (the median and the mode for the whole cohort) in each group varied, with the majority of the severe varus group having an FMA angle of >6° and the majority of moderate to severe valgus group having an FMA angle of <6°. With valgus coronal alignment taken as positive and varus as negative, the Pearson's correlation coefficient for MFT angle with FMA angle was $r=-0.499$ ($p<0.001$) indicating that varus knees tended to have a larger FMA angle and valgus knees tended to have a smaller FMA angle (Fig. 5).

4. Discussion

Our study found a wide distribution of FMA angle in an osteoarthritic population with a mean value of 5.7°, standard deviation 1.2° and range of 7°. This is similar to the results reported by Wang (5.1°, SD 0.9°), Tang (5.7°, SD 1.0°) and Hsu (5.8°, SD 1.9°) for a healthy population [1,8,9]. The median FMA for the severe varus group was similar to the mean reported by Desme for varus knees (7° vs. 6.3° respectively) and the same was true for the moderate to severe valgus group compared to their reported mean for valgus knees (5° vs. 4.7°) [10]. Our study also found a statistically significant difference in the FMA angle between males and females. Tang et al. found that women had lower FMA angles when a distal femoral anatomical axis was used but not when a femoral anatomical axis along the length of the femur was used [9]. Hsu et al. also did not show this difference [1]. This result may therefore be particular to the osteoarthritic population. The direction of this difference, with males having larger FMA, was contradictory to the "perceived wisdom" of males having smaller FMA angles because they tend to be taller. The actual difference was small and the most common value for men and women was still 6° (32% of men and 38% of women). Our study also found a correlation between coronal alignment and FMA angle. This correlation was remarkably similar to that found by Wang ($r=-0.499$ v $r=-0.58$) in a healthy adults of southern Chinese origin [8]. To our knowledge this correlation has not been shown in an osteoarthritic population before.

The limitations of this study are those associated with the inaccuracies of long-leg films. Swanson et al. have shown that up to 40° of limb rotation does not affect the FMA measurement more than 1° but that MFT angle can vary by up to 5° in a fully extended lower limb [18]. However Jiang and Insall found that the FMA varied by 2.5° with a 40° range of rotation [19]. Knee flexion has been shown to increase the valgus angulation of the femorotibal angle measured on knee radiographs [20].

Restoring the mechanical alignment of the lower limb is one of the important aims of TKA surgery. Fang et al. demonstrated neutral post-operative alignment (MFT angle of 0°) correlated closely with implant survival [12]. Historically the acceptable variation from a neutral post-operative lower limb alignment has been often quoted as ±3° or ±5° [5,13–16]. More recently this view had been challenged by a long term follow up study that has shown equal 15 year survivorship in "well-aligned" (±3°) versus malaligned (outwith ±3°) knee arthroplasties [17]. However the authors of this study acknowledged that, in the absence of more evidence to support alternative alignment targets, aiming for neutral alignment was still recommended. Therefore a continued aim is to make the distal femoral cut perpendicular to the mechanical axis of the femur. In order to determine whether this could be reliably achieved with the use of a fixed femoral resection angle for all patients, this study investigated the natural variation in FMA angle.

In terms of achieving appropriate coronal alignment in TKA these data indicate that the use of a fixed valgus resection angle may not be suitable for all patients. An actual bone cut of 6° to the femoral anatomical axis in the study population would fail to achieve a cut

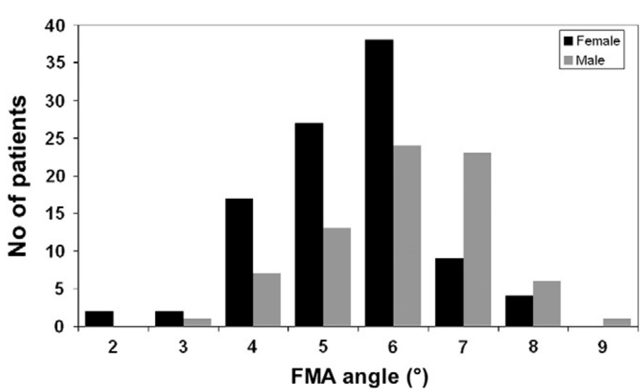

Fig. 4. Distribution of FMA angle with sex.

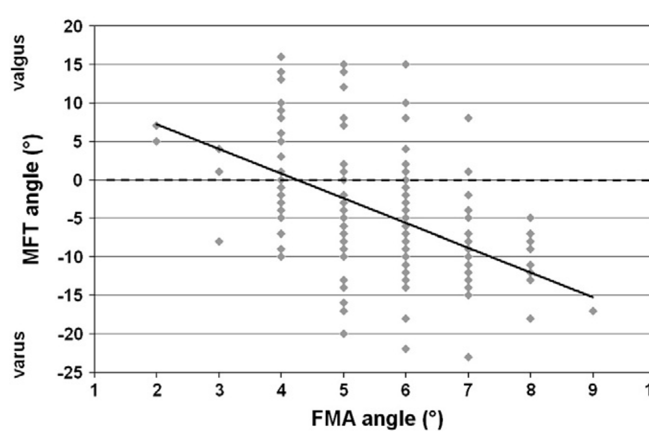

Fig. 5. Correlation between MFT angle and FMA angle.

within 1° of perpendicular to the mechanical axis of the femur in 23% of patients. This supports the study of Bardakos et al. who showed that in at least 30% of patients the 5° to 6° distal valgus cut was not appropriate [4]. Further to this, using 6° would give 80% of males within ±1° of perpendicular but only 75% of females. If the selected distal femoral resection angle for females was reduced to 5° then 83% would be within ±1°. This may therefore suggest that, in the absence of any other information, selecting 5° for females and 6° for males would be the most likely to give a good result. The correlation between MFT angle and FMA angle indicated that for more severe varus deformities or moderate to severe valgus deformities an adjustment of the valgus cut angle could be appropriate. For the moderate varus to mild valgus group a cut of 6° would give 83% knees within ±1° of perpendicular to the femoral mechanical axis, as would a 5° cut. For the severe varus deformities a cut of 6° or 7° would be within ±1° of perpendicular to the mechanical axis for 83% and 78% respectively. However for the moderate to severe valgus deformities 6° would only give 52% within this limit whereas 5° gives 88%. These data imply that even an adjustment of 1° can substantially affect the likelihood of an appropriate cut being made.

This study has given calculated boundaries for coronal deformity groups that have statistically different FMA angles. In applying these to clinical practice, for severe varus knees (9° or greater) the surgeon should consider using a distal femoral resection angle of >6°. For valgus knees (2° or greater) surgeons should consider using an angle of <6° and, as per the practice of Ranawat's group, adjusting the angle to 3° in the severe valgus knee [7]. The traditional 6° distal valgus cut is reliable for moderate varus to mild valgus (8° varus to 1° valgus) coronal deformities. Other sources of an inappropriate distal femoral valgus cut such as the potential errors of misplacing the intramedullary rod into the femoral canal [19] or possible inaccuracies introduced by the saw blade when making the actual cut should also be considered.

Nonetheless, these global “rules of thumb” for patients where nothing is known about the FMA angle would still result in a number of patients having an inappropriate valgus resection. The results of this study show that it is preferable to adjust the distal femoral cut angle according to the individual patient's pre-operative FMA angle. The use of standardised long-leg radiographs to pre-operatively measure patient-specific FMA angles would facilitate this and maximise the chance of obtaining the optimal post-operative leg alignment. The use of computer-navigated surgery is an alternative method of achieving this objective as navigation enables acquisition of joint centres and the identification of the femoral mechanical axis, determining an optimal distal valgus cut for each individual patient. This may be one reason that many studies, including one meta-analysis, have shown fewer outliers with the use of computer navigation when compared to traditional intramedullary instrumentation [21–25].

In conclusion this study found a wide distribution of FMA angle in an osteoarthritic population. There was a statistically significant difference in the FMA angle between males and females with males tending to have larger angles. There was also a correlation between pre-operative coronal alignment and FMA angle with varus knees tending to have larger FMA angles compared to valgus knees. In terms of achieving appropriate coronal alignment in TKA with traditional instrumentation these data indicate that the use of a fixed valgus resection angle is not suitable for all patients and that it may be preferable to adjust the distal femoral cut angle according to the individual patient's pre-operative FMA angle or according to the pre-operative coronal alignment if measurement of this angle is not available.

5. Conflict of interest statement

None of the authors have any employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations or received grants or other funding that are related to this study.

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