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In vitro study of inter-individual variation in posterior slope in the knee joint

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ABSTRACT

Background: The posterior tibial slope of the knee is an issue in total knee arthroplasty. It has also been suggested to be a determinant for the difference in the incidence of anterior cruciate ligament rupture between males and females. The current literature features discrepancies in inter-individual variation in posterior slope and the effect of gender. This in vitro study was aimed at quantifying the inter-individual variations of the posterior tibial slope and the gender difference.

Methods: The slope of the medial tibial plateau of 61 male and 44 female, bare human tibias was measured in three sagittal planes, separated by 5 mm, with the use of a custom-made device. The effect of measurement location, gender and ethnicity was determined with analysis of variance.

Findings: The difference between the measurement locations was statistically significant but smaller than the variation between specimens. The mean posterior slope was 8.4° (SD 3.7°), 95% confidence interval was 1.0–5.8°. Ethnicity did affect posterior slope ($p = 0.001$), but gender did not reach significance ($p = 0.091$).

Interpretation: The results support the existence of a substantial inter-individual variation in posterior slope. For total knee arthroplasty, the pre-operative posterior slope is apparently not compatible with the suggestion not to cut a slope greater than 8°, as more than half of the tibias had a greater slope. Secondly, part of the variance over subjects is related to ethnicity and possibly also to gender, which might have implications for the risk of sustaining an anterior cruciate ligament rupture and for the success of total knee arthroplasty.

1. Introduction

The posterior tibial slope of the knee joint is considered an important feature in total knee arthroplasty (TKA) as it affects the mechanics of the knee joint (Kuwano et al., 2005; Singerman et al., 1996; Wasielewski et al., 1994; Hofmann et al., 1991; Whiteside and Amador, 1988). Basically, it affects the resulting shear forces at the joint when it is loaded by muscle forces or external forces. Furthermore, a greater posterior slope increases varus and valgus laxity, antero-posterior laxity and rotational laxity in the knee joint (Jojima et al., 2004). A larger posterior slope also results in a larger range of knee motion by loosening of the posterior cruciate ligament when the knee is flexed (Whiteside and Amador, 1988). In a study on total knee prostheses, Migaud et al. (1996) concluded that the posterior tibial slope has more effect on anterior tibial translation than ACL preservation.

Since the ACL is strained during anterior tibial translation, the posterior tibial slope might also affect the load that the ACL is subjected to during exercise (Fig. 1). Therefore, the degree of posterior tibial slope might be one of the determinant factors for ACL rupture.

As a consequence of its mechanical effects, the posterior slope is related to some post-operative problems in TKA. An inappropriate cutting angle, resulting in an incorrect posterior slope, is associated with component subsidence, increased strain in the posterior cruciate ligament and polyethylene wear (Singerman et al., 1996; Wasielewski et al., 1994; Hofmann et al., 1991). Although the cutting angle in TKA is still controversial, it is suggested to cut parallel to the pre-operative anatomical posterior slope, rather than to use a predetermined cutting angle (Matsuda et al., 1999; Jiang et al., 1994; Hofmann et al., 1991; Moller et al., 1985). However, studies on this topic show a wide inter-individual variation in posterior slope, suggesting the need to determine the pre-operative cutting angle individually. Almost all previous studies measured the posterior slope on radiographic images. So far only Moller et al. (1985) measured the posterior slope in cadaveric knees of 30 individuals. Using radiography, two of the six reference axes examined by Brazier et al. (1996) proved to be influenced by gender. Gender differences could be related to the higher incidence of ACL rupture in females (Prodromos et al., 2007).

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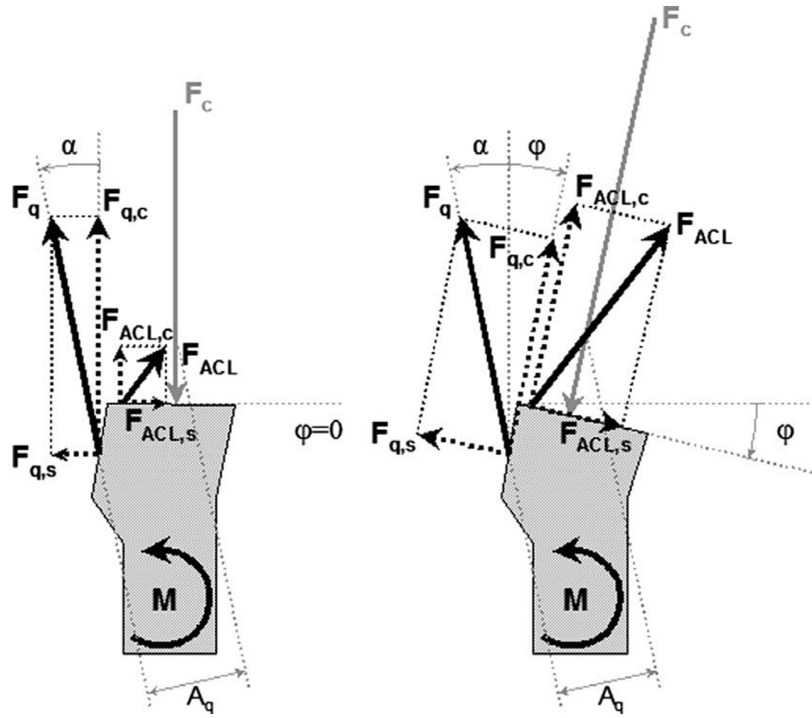

Fig. 1. Schematic representation of the force balance at the knee in the sagittal plane with an externally applied flexion moment M. The flexion moment is balanced by the patellar tendon force (F_q) resulting from the force in the quadriceps muscle: $F_q = M/A_q$ with A_q being the moment arm of the patellar tendon. The shear component $F_{q,s}$ of F_q, i.e. the component parallel to the tibial plateau, is balanced by the shear component ($F_{ACL,s}$) of the force in the anterior cruciate ligament (F_{ACL}). The compression force F_c is the resulting compressive reaction force of the femur on the tibia due to the components of F_q and F_{ACL} normal to the tibial plateau, i.e. $F_{q,c}$ and $F_{ACL,c}$. The assumption of this simple model is that the patellar tendon force direction (α) and anterior cruciate ligament force direction remain constant relative to the long axis of the tibia with variation of the posterior slope φ. The variation of the posterior slope only affects the components of F_q and F_{ACL}. A simple analysis of moment and force balance will show that the magnitude of $F_{q,s}$ depends on the posterior slope φ. For larger values of φ, $F_{q,s}$ increases, resulting in a higher F_{ACL} to produce the counter balancing shear force $F_{ACL,s}$. In the figure, it can be deducted that if φ goes to zero, the direction of $F_{q,s}$ is more horizontal and the magnitude of $F_{q,s}$ will therefore become smaller.

Most previous studies concentrated on the medial tibial plateau, as it is generally considered the major load-bearing compartment of the tibial plateau. In contrast to the lateral tibial plateau, its geometry suits the requirements necessary to obtain accurate measurements on posterior slope, as it is relatively flat with only little concavity and provides the proper landmarks to make measurements on bone preparations or on X-ray images.

This study was aimed at the quantification of the inter-individual variations of the posterior tibial slope and of the differences between genders. A custom-made device was used to measure the posterior slope directly on the tibial bone. A large number of specimens was used, in order to determine the inter-individual variability in tibial slope angle. The measurements directly on the bone allowed the measurement of the slope of the medial tibial plateau at three locations on the plateau. Furthermore, test-retest measurements were performed for determining the reproducibility of the measurements.

2. Methods

2.1. Material

Hundred and five left human tibias, collected at the ossuary of the division of Anatomy and Histology at the University of Stellenbosch, South Africa, were included. Bones that were deformed by osteophytes, previous fractures, malpreservation or unknown gender did not meet inclusion criteria for this study. A total of 105 bones from 61 males and 44 females were measured. Equal numbers for males and females could not be obtained, as there were less female than male specimens available. According to the previous South-African registration, the ethnic origin of 30 bones was African (20 males, 10 females), of 34 bones Caucasian (20 males, 14 females), and of 41 bones it was mixed (neither African nor Caucasian, 21 males, 20 females).

The bare tibias had been cooked for preservation and were free of cartilage, menisci or any other soft tissue. It was unknown if the donors suffered any kind of knee complaint during life. The age at death was unknown for three specimens. The average age at death of the 102 other donors of the bones was 56 (SD 16) years.

2.2. Measurements

The tibias were fixed in a clamp. A custom-made device was used to represent and measure the posterior slope in an anterior posterior direction in a sagittal plane with the tibial shaft anatomical axis (TSAA) as a reference (Fig. 2a). To represent the tibial slope, the proximal part of the measurement device created a virtual line by connecting the anterior and posterior bony ridges of the medial tibial plateau. Care was taken to obtain the tibial slope in a sagittal plane, by taking into account the antero-posterior elliptical shape and the lateral margins of the plateau and the tibia as a whole. The posterior slope of the medial tibial plateau was measured in three parallel sagittal planes: one in the middle of the plateau and 5 mm medial and lateral to this location. The TSAA in the sagittal plane was created by the use of two points. One point was obtained by projecting the middle of the medial intercondylar eminence upon the side of the medial plateau, in a lateral view (A in Fig. 2a). The second point was the middle of the medial malleolus measured at its most distal end (B in Fig. 2a). The white line on the measurement device was positioned over these two points and represents the TSAA (Fig. 2a). The angle between the line perpendicular to the TSAA and the