FUNCTIONAL FLEXION AXIS OF THE KNEE IN 3-D SPACE

INTRODUCTION:
Locating the true flexion-extension (FE) axis of the knee can play an important role in femoral component placement in total knee arthroplasty (TKA), especially using designs incorporating a single radius of curvature. A fixed axis FE within the distal femur has been documented in several studies (Elias et al, 1990; Hollister et al, 1993; Churchill et al, 1998; Eckhoff et al, 2001). Traditionally, the fixed FE axis has been approximated using the trans-epicondylar (TE) axis, a line joining the medial and lateral femoral epicondyles (Churchill et al, 1998), however, a recent study has shown this approximation to be inadequate due to the low predictability of the TE axis (Katz et al, 2001). A better approximation of the FE axis has been shown to be the axis of cylinders (cylindrical axis) fit to the posterior condyles of the femur (Eckhoff et al, 2001). The purpose of this study is to determine if there is a significant difference between the commonly used TE axis and the cylindrical axis in 3-D space as well as in the more clinically applicable transverse and coronal planes.

METHODS:
23 fresh frozen cadaveric distal femurs (10 male, 48-66 yrs, 13 female, 48-91 yrs) with intact soft tissue were imaged in 0.5 mm slices via Computed Tomography (CT). Volumetric CT data were reconstructed in 3-D virtual space with custom written software (Figure 1). The epicondyles were identified in 3-D space as the most prominent medial and lateral points of the femoral condyles and the TE axis was created by passing a line through these two points (Figure 1). Computer generated cylinders were manually fit within the confines of the posterior medial and lateral femoral condyles to confirm and mark the cylindrical geometry of the condyles (Figure 2). Passing a line through two points representing the center of the cylinders created the cylindrical axis.

The 3-D coordinates where the TE axis and the cylindrical axis intersect the medial and lateral surfaces of the femur were recorded. From these coordinates the equation of a line in 3-D space was determined for both axes. The angle between the TE axis and the cylindrical axis was calculated using the dot product. To appreciate the relationship between these axes in the traditional coronal and transverse planes, projections of the axes from 3-D space onto the traditional orthogonal planes was accomplished in the following manner: The X-axis was defined as the cylindrical axis. A line passing through the center points of the most proximal and distal transverse images of the femoral shaft was defined as the Z-axis. A line perpendicular to both of these axes was the Y-axis. The X-Z axes defined the frontal plane and the X-Y axes defined the transverse plane. The TE and cylindrical axes were projected onto the coronal and transverse planes and the angle between them calculated.

One sample t-tests were run with GraphPad InStat (GraphPad Software, San Diego, CA) to determine if there was a significant difference between the TE axis and the cylindrical axis in 3-D space, the frontal and transverse planes. Differences were considered significant with $p < 0.05$.

RESULTS:
All three of these measured angles were statistically significant with $p < 0.05$. The average angle between the TE and cylindrical axis in 3-D space was $4.6^\circ$ (standard deviation $1.8^\circ$, range $1.8^\circ$ to $11.3^\circ$). In the frontal plane the TE axis varied from the cylindrical axis by $1.8^\circ$ (standard deviation $1.34^\circ$, range $0.1^\circ$ to $3.9^\circ$) and in the transverse plane by $2.3^\circ$ (standard deviation $1.49^\circ$, range $0.2^\circ$ to $5.2^\circ$).

DISCUSSION:
Significant differences between the TE axis and cylindrical axis were shown in this study but they may not be appreciated clinically because of their small magnitude. However, the variable relationship of the TE axis to the cylindrical axis has significant implications for TKA. The cylindrical axis is by definition equidistant from the articular surface of the femoral condyles while the TE axis is not. In TKA, a distal femoral cut made according to the highly variable TE axis could produce significant mal-alignment leading to soft-tissue imbalance and altering contact pressures. In a recent study it was shown that 3 degrees of mal-alignment of the femoral component more than double the pressures on the medial compartment and increased peak contact pressure by 68% (Guettler et al, 2002). Increased pressures would ultimately result in increased wear, decreased implant longevity, and possible need for revision TKA.

The method of fitting cylinders to the posterior femoral condyles in 3-D space employed in this study may be considered a novel concept with little support in the literature. However, this is an extension of 2-D studies that have shown the posterior femoral condyles to be circular in shape when viewed in the sagittal plane when analyzing the geometry of the articular surface of the distal femur using non-destructive (CT, MRI, digitization, and fluoroscopy) and destructive (dissection and cryosection) methods (Freeman et al, 2005).

This study has shown that there is a significant difference between the cylindrical axis and the trans-epicondylar axis. This difference could have significant implications for soft tissue balancing which impact function and longevity in TKA.

REFERENCES:

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