Can an Artificial Knee Reproduce Normal Anatomic Motion ? An Experimental Simulation Study

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INTRODUCTION: Achieving anatomic motion is an important design criterion for an artificial knee, as it will produce normal soft tissue lengths and muscle lever arms throughout the flexion range. In addition, it is important to provide the normal amount of anterior-posterior and internal-external laxity about the neutral path, in order to avoid stiffness and facilitate a variety of functions and movements. However, fluoroscopic studies have shown that artificial knee designs which are the most widely used today, do not achieve normal motions and laxities. In particular the fan pattern of the neutral path, where the medial contact point remains close to a fixed position, while the lateral contact moves from anterior to posterior from extension to full flexion; is not reproduced. It was proposed that in order to achieve anatomic motion, as well as utilising lateral and medial bearing surfaces, the addition of an intercondylar bearing is needed. This would apply especially in designs without the cruciate ligaments. This proposition was investigated using new design methodology and a specially designed test machine.

METHODS: A standard femoral component was designed based on the average 3D shapes from 100 MRI scans of early arthritic knee, from an NIH study. Small modifications were made including averaging the medial and lateral sagittal profile to a constant radius. Standard tibial components were designed to be representative of the following types: PS (posterior stabilized), Ultracongruent, Medially Congruent, and Medial Pivot. For the Intercondylar design, in the central third of the femoral component, a cylindrical bearing was added, eccentric from the lateral and medial bearing surfaces. To design the tibial bearing surfaces, the femoral component was moved through a multiplicity of flexion and rotational angles, consistent with normal anatomic motion with the superposition of laxity. All of these designs were intended for use without the cruciate ligaments. Components were made by 3D printing. A Test Machine was constructed which applied an axial force, and anterior-posterior and internal-external forces, representing functional values. The displacements of the femoral condyles on the tibial surfaces were measured. This was plotted as transverse lines across the tibial surface at each angle of flexion. Anatomic patterns in the literature were used as the benchmark.

RESULTS:

For all of the standard components, the transverse lines were the same at all angles of flexion. For the PS and Ultracongruent, the laxity lines were parallel and the same for medial and lateral. The lines for the PS displaced posteriorly in high flexion. For the Medial Pivot and Medially Congruent, there were fan-shaped laxity lines, but the same at all flexion angles. However for the Intercondylar design, the fan-shaped transverse lines were internally rotated in extension progressing to externally rotated in high flexion, just as in the Anatomic Knee. In all designs, the laxity, shown by the spacing between the transverse lines from anterior-posterior forces, or internal-external rotation, could be varied by changing the sagittal radii of the lateral and medial bearing surfaces. However there was a clear difference between the standard designs and the Intercondylar, the former not showing anatomic motion characteristics; the latter showing normal patterns.

DISCUSSION AND CONCLUSION:

The Artificial Knee designs used most commonly today, produce satisfactory clinical results in the large majority of patients. However there are limitations in that fully normal function is not usually achieved, while there is often some residual pain or discomfort, especially after exercise. These limitations may be due in part to a lack of normal anatomic motion being achieved. This deficiency is likely to result in abnormal ligament and soft tissue lengths and tensions, as well as abnormal patella tracking. It is possible that improvements can be made to the outcomes if normal anatomic motion could be achieved. It was demonstrated that a possible approach to achieving this is a design where the bearing surfaces facilitate such anatomic motion. Such a design, with an intercondylar bearing surface, can provide such motion. Clearly, further studies are indicated, such as demonstrating normal kinematics in knee specimens and then ultimately in patients.