Introduction

How total knee arthroplasties (TKA) articulate is directly related to their functional and wear performance. Recently, there has been significant interest in the center of axial rotation, or pivot point of the knee. Since the tibia exhibits internal rotation with knee flexion, the pivot point is inextricably linked to anterior/posterior translations of the femur with respect to the tibia; a medial pivot implies posterior translations of the femur with flexion, a lateral pivot implies anterior femoral translations with flexion. The purpose of this study was to describe the average location of the pivot point, as related to TKR design, in a large number of knees studied under dynamic weight-bearing conditions.

Methods

This study was conducted at 14 venues and included patients from 21 surgeons using 21 different articular designs. Subjects gave informed consent to participate in the protocol, as approved by each institutional review board. 215 well functioning TKA’s were studied using fluoroscopy as subjects performed a dynamic stair ascent. There were 131 cruciate retaining fixed bearing knees (11 TKA designs), 44 mobile bearing knees (6 TKA designs), and 40 posterior stabilized knees (4 TKA designs). CAD model based shape matching was used to determine 3D knee kinematics and the locations of medial and lateral tibio-femoral contact (22,907 fluoroscopic images). The center of axial rotation was determined for each trial by solving the least-squares system of equations describing the lines connecting the medial and lateral contact locations over the entire motion. The medial/lateral location of the center of axial rotation was normalized to the width of each tibial component, and expressed as a percentage of tibial width, -50% (medial) to +50% (lateral).

Results

Posterior stabilized knees exhibited medial pivots (mean +14%, range +7% to +30%) while cruciate retaining (mean -9%, range -35% to +21%) and mobile bearing knees (mean –19%, range -48% to +5%) exhibited lateral pivots on average (Table 1, Figures 1,2). Cruciate retaining fixed bearing knees exhibited slightly more axial rotation than did posterior stabilized knees.

Table 1. Computed medial/lateral locations of the pivot point, or average center of axial rotation.

<table>
<thead>
<tr>
<th>Implant Type</th>
<th># Knees</th>
<th># Images</th>
<th>Average Range of Axial Rotation (deg)</th>
<th>Med/Lat Center of Rotation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>40</td>
<td>4133</td>
<td>7.9 ±1.5</td>
<td>+14% ± 9%</td>
</tr>
<tr>
<td>CR</td>
<td>131</td>
<td>14646</td>
<td>9.3 ±2.1</td>
<td>-9% ± 16%</td>
</tr>
<tr>
<td>MB</td>
<td>44</td>
<td>4128</td>
<td>8.6 ±1.0</td>
<td>-19% ± 15%</td>
</tr>
</tbody>
</table>

KW-ANOVA on Ranks, Dunn’s (p<0.05)

CR > PS PS > CR > MB

Discussion

How a TKA design provides A/P stability dictates the location of its center of axial rotation and the A/P motions of the condyles. PS knees, which force the femur posterior with flexion, exhibited a net medial center of pivot. The CR knees, which included articulations with a broad range of sagittal conformity, exhibited a lateral center of rotation on average. CR designs with greater sagittal conformity exhibited more central pivot locations. The mobile bearing designs, which included rotating & translating and rotating-only bearings, exhibited lateral pivot locations. All of the rotating-only MB designs were relatively unconstrained for flexion beyond 20 or 30 degrees, and exhibited top-side anterior femoral translation with flexion.

Tibio-femoral axial rotation and anterior/posterior motion determine the pivot point of the knee. In total knee arthroplasty it is possible to control anterior/posterior motion, through either condylar conformity or cam mechanisms, and therefore dictate the average location of the pivot point.

Acknowledgments

The authors gratefully acknowledge the following individuals for their participation in and facilitation of these studies over the past 13 years: Anne Banks, Sherry Backus, Johan Bellemans, Leigh Breslauer, Fabio Catani, James D’Antonio, Gary Davidson, Kevin Deluzio, Lewjack Dorrance, Tomas Drobný, Silvia Fantozzi, Steven Haas, Melinda Harman, William Harris, Fraser Harrold, Anthony Hedley, Robyn Kabbaz, Ryutaku Kaneyama, Mark Kester, Richard Laskin, Alberto Leardini, Gerhard Luder, Raul Marquez, Phillip Merritt, Hideshige Moriya, Urs Munzinger, Michael Piazza, James Otis, Hiroyuki Nozaki, Donald Reilly, Christoph Reinschmidt, Alex Stacoff, Tohru Suguro, Jan Victor, Leo Whiteside, David Wilson, Urs Wyss.

Figure 1 – Example of the kinematics of one design or posterior stabilized knee with a net medial center of rotation at +29%. The figure shows the size-normalized locations of condylar contact on the tibial insert (black dots), and the computed centers of axial rotation for each trial (gray dots). The white cross indicates the locus of the average center of rotation for all trials, and the length of each arm of the cross indicates the standard deviation.

Figure 2 – Example of the kinematics of one design of mobile bearing knee with a net center of rotation at –17%. See Figure 1 legend for explanation.

These data are useful to understand the function of existing TKA designs and for considering options in the evolution of new total knee arthroplasty designs.