Effect of Implant Alignment on Contact Force after Total Knee Arthroplasty: In Vivo Validated Computer Model

INTRODUCTION

Component alignment after total knee arthroplasty has been heavily researched. It is widely accepted that deviations from the recommended alignment of 0° of varus for the tibial tray and 5-7° of anatomic valgus for the femoral component can lead to complications such as accelerated component wear and damage and implant loosening. This is primarily attributed to alterations in the distribution of contact force across the tibiofemoral and patellofemoral compartments and the transmission of these contact forces to the underlying implant-cement-bone interfaces. Most of the associations between implant alignment and contact forces have been made using computer modeling. The purpose of this study was to use a computer model validated in vivo to evaluate the relationship between the component alignment and the contact force.

METHODS

Patients: One patient (male: right knee, 80 years, 67 kg) received a custom tibial prosthesis instrumented with four uniaxial force transducers and a telemetry system. The tibial bone cut was made at 90° to the long axis in the coronal plane. The distal femoral cut was made at 6° valgus to the anatomic axis of the femur; the posterior femoral cut in 3° external rotation with reference to the posterior condyles. In vivo knee contact forces, ground reaction forces, and knee kinematics were measured during squatting performed up to knee flexion angle that was within patient’s tolerance (~80°).

Subject-Specific Computer Model

Figure 1: Preoperative CT scans were reconstructed to extract tibiofemoral bone geometry using MIMICS (Materialise, Belgium). CAD models of the components were directly aligned to the 3D bone models.

The subject’s anthropometric measurements were used to scale the body segments and 16 muscles were constructed for each lower limb. 3D surface models of the knee with implants was used to model the knee joint. Contact was modeled between tibiofemoral and patellofemoral articular surfaces. Knee ligaments (medial collateral ligament <MCL>, lateral collateral ligament <LCL>, and posterior cruciate ligament <PCL> were modeled with nonlinear springs). The attachments of these ligaments were adjusted to subject-specific anatomic landmarks and material properties were assigned from published reports. The quadriceps tendon and patellar ligament were modeled with contact-based elements to simulate contact and wrapping around the trochlear groove and tibial insert respectively.

Figure 3: The measured kinematics were used to drive the motion of the body segments, and individual muscle lengths were monitored. The recorded muscle lengths were then used to generate a forward dynamics simulation. Tibiofemoral and patellofemoral contact forces during squatting were computed.

Tibiofemoral and patellofemoral contact force was computed with (1) neutral (implanted) condition; (2) the femoral component axially malrotated ±5° relative to the neutral condition; and (3) the tibial tray malaligned ±5° in the coronal plane relative to the neutral condition.

RESULTS

Model predicted peak tibiofemoral contact force was 2.0 xBW (times bodyweight) which was close to that measured in vivo (1.9 xBW).

Table 1: Ligament and Muscle Tension Forces (Newtons)

<table>
<thead>
<tr>
<th></th>
<th>MCL</th>
<th>LCL</th>
<th>Quadriceps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>137.3</td>
<td>110.8</td>
<td>867.3</td>
</tr>
<tr>
<td>Valgus Tibial Tray</td>
<td>151.2</td>
<td>229.9</td>
<td>861.7</td>
</tr>
<tr>
<td>Varus Tibial Tray</td>
<td>245.8</td>
<td>117.1</td>
<td>1312.9</td>
</tr>
<tr>
<td>Femoral Int Rot</td>
<td>219.0</td>
<td>69.5</td>
<td>1833.7</td>
</tr>
<tr>
<td>Femoral Ext Rot</td>
<td>166.3</td>
<td>222.7</td>
<td>888.8</td>
</tr>
</tbody>
</table>

DISCUSSION

The importance of implant alignment on clinical outcomes has already been shown and major technical advances are being made to improve the accuracy of implant alignment. However, very little quantitative evidence exists in relating the magnitude of malalignment to its effect on contact forces. Most of the theoretical associations between suboptimal component alignment and abnormal forces have been demonstrated in computer models that have not been validated with experimental data. To bridge this gap we developed and validated a subject-specific model that accurately predicted the femorotibial contact force based on in vivo data. To our knowledge this is the first model of squatting that has been validated with in vivo tibiofemoral contact force.

Tibial component varus led to a greater increase in tibiofemoral and patellofemoral contact forces than valgus. This is supported by clinical reports of poorer outcomes with varus malalignment compare to valgus malalignment. Internal malrotation of the femoral component led to the greatest increase in tibiofemoral and patellofemoral forces. These differences in contact force were related to differences in tension between MCL and LCL as a result of imbalance of the knee joint.

A validated subject-specific computer modeling approach can be used to not only determine the optimal alignment to match the patient’s anatomy but also to the patient’s kinematics and loading pattern. Developments in modeling wear damage in biomaterials and remodeling in bone will also be extremely valuable.

REFERENCES

1) D’Lima DD et al, Clin Orthop, 2005