INTRODUCTION

The success of total knee arthroplasty has contributed to its widening application to a younger, more active patient population whose daily regimen includes more demanding high flexion activities. Worldwide expansion to Middle Eastern and Asian patient populations, where the attainment of high knee joint flexion is often a cultural requirement, has been steadily increasing in recent years. This study reveals the contact areas and stresses that are associated with polymer insert abrasion in four total knee designs during the most highly loaded portions of three different high flexion activities, and suggests their efficacy in clinical use.

Three mobile bearing designs were evaluated, the Dual Bearing Knee (Finsbury Orthopaedics Ltd.), e.motion (Aesculap AG & Co.KG), and P.F.C. Sigma RPF (DePuy, a Johnson & Johnson Company) in addition to the Legacy LPS-Flex Fixed Bearing (Zimmer, Inc.). The latter two designs are currently available for clinical use in the United States.

METHODS

A three-dimensional, finite element model was created for each total knee design by measuring the articular surfaces of implantable quality parts using a laser profilometer. Maximum joint loads and the angle of knee flexion that they occur at were determined through a meta-analysis of the literature for three high flexion activities; stair ascent\(^1,2,3,6\) (60°), rising from a chair\(^4\) (90°) and rising from a double leg kneel\(^5,6,7\) (135°) using a body weight of 71 kg. The loads were applied and the virtual components were allowed to settle into their preferred alignments without friction or consideration of soft tissue constraints. To aid in comparison, all polymer inserts were characterized by the same gamma irradiated, nonlinear material\(^8\) of 10 mm thickness maintained at 37°C. Contact areas and stresses on the polymer inserts were calculated using a 1 MPa threshold and their magnitudes and locations were then photorealistically imaged.
The distribution of compressive normal (contact) stresses is appreciated from a superior posterior view of the left knee for the systems studied during each activity. These images give an indication of areas of stress distribution.

**Dual Bearing Knee**

Contact Area: 621 mm²  
Stair Ascent: 60° Flexion  
Femoral Forces: 4.3 BW Inferior, 0.2 BW Posterior

Contact Area: 455 mm²  
Chair Rise: 90° Flexion  
Femoral Forces: 3.3 BW Inferior, 1.0 BW Anterior

Contact Area: 292 mm²  
Kneel Rise: 135° Flexion  
Femoral Forces: 4.5 BW Inferior, 0.4 BW Anterior

**e.motion**

Contact Area: 831 mm²  
Stair Ascent: 60° Flexion  
Femoral Forces: 4.3 BW Inferior, 0.2 BW Posterior

Contact Area: 484 mm²  
Chair Rise: 90° Flexion  
Femoral Forces: 3.3 BW Inferior, 1.0 BW Anterior

Contact Area: 345 mm²  
Kneel Rise: 135° Flexion  
Femoral Forces: 4.5 BW Inferior, 0.4 BW Anterior
where surface abrasion caused by contact with the femoral component can occur. The higher the contact stresses, the greater the propensity for abrasive damage. Stresses visualized on the sides of the insert are indicative of contact occurring on the distal surface near the perimeter. Designs are presented in alphabetical order.

**Legacy LPS-Flex Fixed**

Contact Area: 277 mm²  
Stair Ascent: 60° Flexion  
Femoral Forces: 4.3 BW Inferior, 0.2 BW Posterior

Contact Area: 311 mm²  
Chair Rise: 90° Flexion  
Femoral Forces: 3.3 BW Inferior, 1.0 BW Anterior

Contact Area: 335 mm²  
Kneel Rise: 135° Flexion  
Femoral Forces: 4.5 BW Inferior, 0.4 BW Anterior

**P.F.C. Sigma RPF**

Contact Area: 338 mm²  
Stair Ascent: 60° Flexion  
Femoral Forces: 4.3 BW Inferior, 0.2 BW Posterior

Contact Area: 323 mm²  
Chair Rise: 90° Flexion  
Femoral Forces: 3.3 BW Inferior, 1.0 BW Anterior

Contact Area: 287 mm²  
Kneel Rise: 135° Flexion  
Femoral Forces: 4.5 BW Inferior, 0.4 BW Anterior
DISCUSSION

The Dual Bearing Knee and e.motion cruciate retaining designs display highly conforming geometries during stair ascent with stresses lower than most total knees at full extension\(^9\). The Legacy LPS-Flex Fixed and P.F.C. Sigma RPF designs feature a polymer spine that interacts with a femoral cam to guide contact posteriorly in high flexion and are, in general, less conforming than the cruciate retaining designs and present with higher stresses.

The large anteriorly directed femoral force in chair rise is handled differently by each type of design in this study. The anterior slopes of the Dual Bearing Knee and e.motion polymer inserts constrain the motion, creating large contact areas with low stresses. The polymer spines in the Legacy LPS-Flex Fixed and P.F.C. Sigma RPF designs offer anterior motion constraint when engaged by their respective femoral cams, resulting in a more central contact location.

Of the three high flexion activities evaluated, kneel rise is the most demanding. Each of the designs studied displays stresses above the yield point reported for the polymer material. It is possible that these high stresses may cause permanent deformation of the polymer insert when patients are engaged in prolonged activities in this position. Fluoroscopy studies\(^{10}\) of total knees have shown that the more posterior the contact location on the polymer insert, the more flexion the patient can experience. Although the spine cam designs successfully achieve this, they do so at the expense of higher stresses when compared to the e.motion cruciate retaining design.

CONCLUSIONS

In general, the cruciate retaining designs in this study realize lower stress levels than the spine cam designs in high flexion activities. The e.motion design maintains the highest conformity for all three high flexion activities in this study, resulting in the lowest stresses in the polymer insert. However, the maximum amount of flexion that a patient might experience may be less than the spine cam designs that force the location of femoral contact more posterior.

As contemporary total knee designs evolve to address the increased demands of younger and more culturally diverse patient populations, they will need to expand their range of motion envelope. Additionally, forces in the knee joint during high flexion activities vary considerably among patients and will be further influenced by component placement and soft tissue balancing. This information should assist manufacturers in ongoing design optimization required to assure the safety and effectiveness of these systems.

REFERENCES