TIBIAL PLATEAU ABRASION IN MOBILE BEARING KNEE SYSTEMS DURING WALKING GAIT II: A FINITE ELEMENT STUDY

Edward A. Morra, M.S.M.E.
Paul D. Postak, B.Sc.
Christine S. Heim, B.Sc.
A. Seth Greenwald, D.Phil.(Oxon)

Orthopaedic Research Laboratories
Lutheran Hospital
Cleveland Clinic Health System

INTRODUCTION

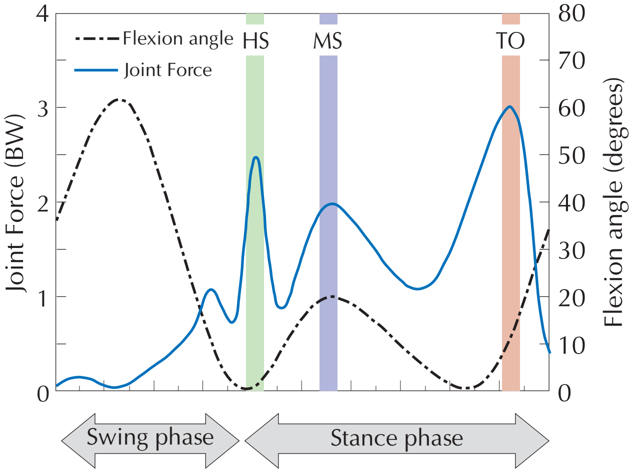
The abrasion observed in Ultrahigh Molecular Weight Polyethylene (UHMWPE) total knee arthroplasty component retrievals is the result of high cyclical loads, which act on the tibial plateau during daily ambulation. This dynamic process influences *in vivo* component longevity and is dependent on the magnitude and distribution of contact stresses on the tibial plateau. Mobile bearing knee systems offer increased component conformity over their fixed plateau counterparts and thus diminish the magnitudes of these contact stresses.

This study reveals the contact areas and stresses that are associated with tibial plateau abrasion in four mobile bearing knee designs during three highly loaded points in the walking gait cycle, and suggests their efficacy in clinical use.

The four systems studied include the Innex UCOR (Sulzer Orthopedics Ltd.), Interax (Stryker Howmedica Osteonics), PFC Sigma RP Curved and PFC Sigma RP Stabilized (DePuy, a Johnson & Johnson Company). The latter two designs are currently available for clinical use in the United States, the former two systems, however, enjoy a growing international presence.

METHODS

A three-dimensional, finite element model was created for each mobile bearing design by measuring the articular surfaces of implantable quality parts using both a coordinate measuring machine and a laser profilometer. A body weight (BW) of 74 kg (163 lbf) was used in this evaluation corresponding to an average 60-year old, 5′ 8″ male subject.[1] The average loading conditions for the heelstrike, midstance and toeoff portions of the stance phase of the walking cycle were simulated under optimal alignment. All of the UHMWPE plateaus were characterized by a gamma irradiated, nonlinear material[2] of 10 mm thickness maintained at 37° Celsius. Contact areas and stresses on the tibial plateau were calculated and their magnitudes and locations were then photorealistically imaged.



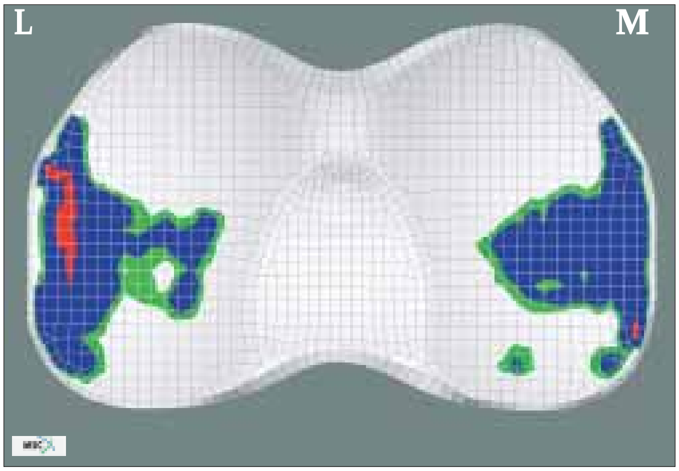
Walking Gait Cycle	Normal Joint Force	Knee Flexion Angle
Heelstrike	2.5 BW (1950 N)	0 degrees
Midstance	2.0 BW (1560 N)	20 degrees
Toeoff	3.0 BW (2540 N)	15 degrees

PROXIMAL CONTACT STRESS

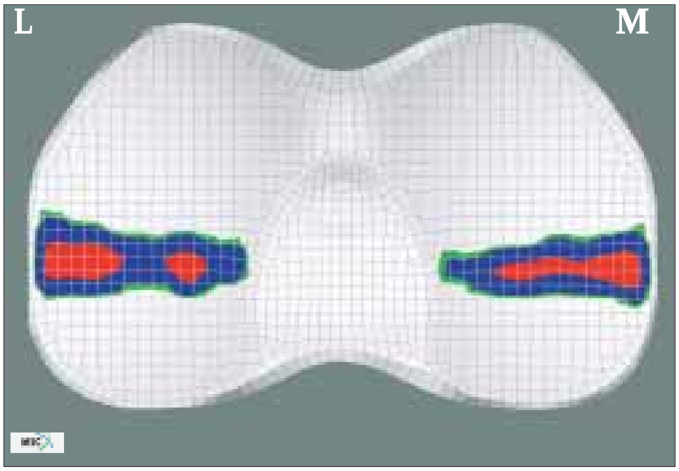
*1 MPa = 1 N/mm^2 = 145 psi

The distribution of compressive normal (contact) stresses is appreciated from a superior view of the left knee for the systems studied during the walking gait cycle. These images give an indication of areas where surface abrasion caused by contact with the femoral component can occur during the heelstrike, midstance

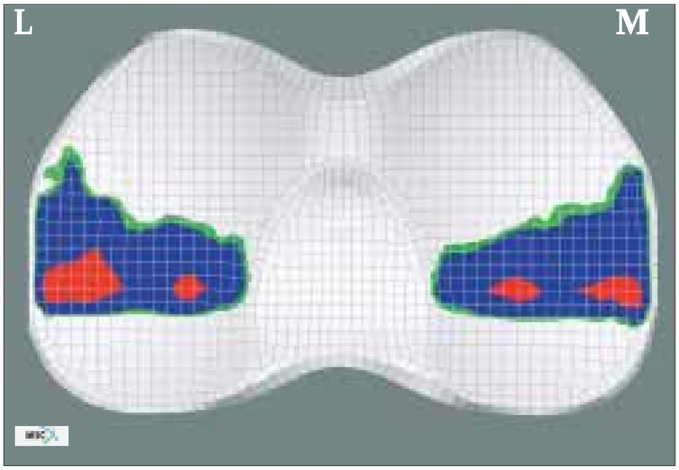
Innex UCOR



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 551 mm^2

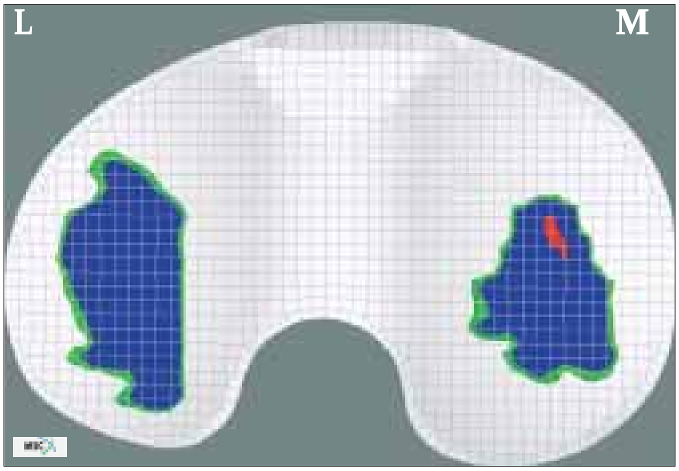


Midstance: 2.0 BW, 20° flexion
Contact Area: 294 mm^2

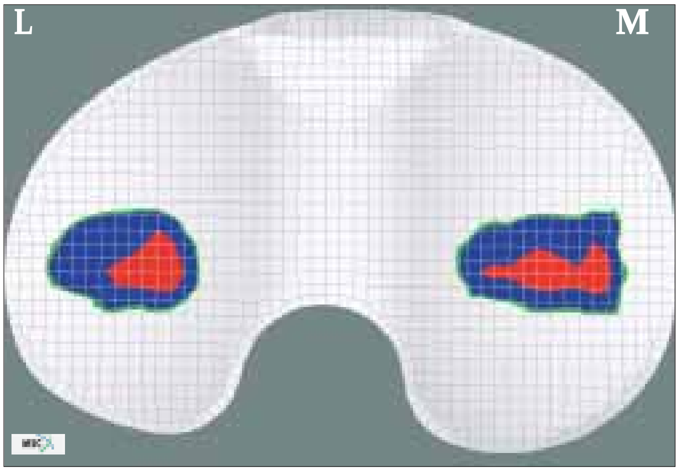


Toeoff: 3.0 BW, 15° flexion
Contact Area: 514 mm^2

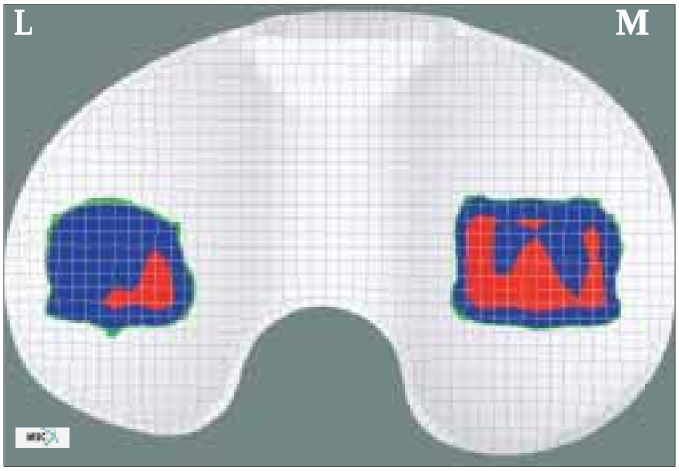
Interax



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 530 mm^2



Midstance: 2.0 BW, 20° flexion
Contact Area: 308 mm^2

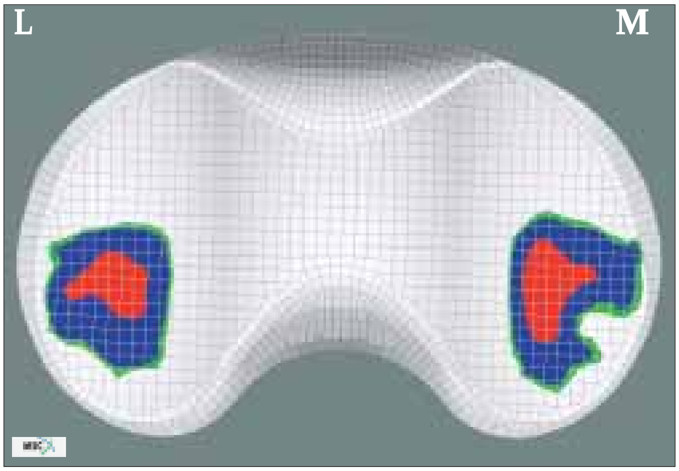


Toeoff: 3.0 BW, 15° flexion
Contact Area: 408 mm^2

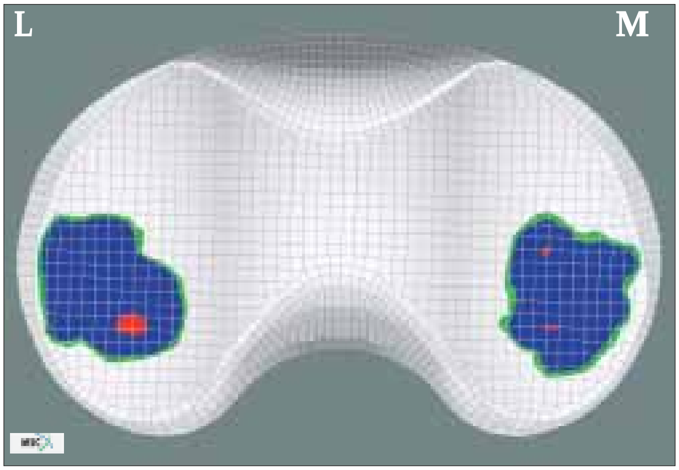
and toeoff positions. The higher the contact stresses the greater the propensity for abrasive damage. The proximal contact areas are determined using a 1 MPa threshold. Designs are presented in alphabetical order for each flexion angle.

In viewing the contact patterns, it should be appreciated that it is not their size that is predictive of successful *in vivo* performance, but rather the magnitudes and manner by which the contact stresses are distributed.

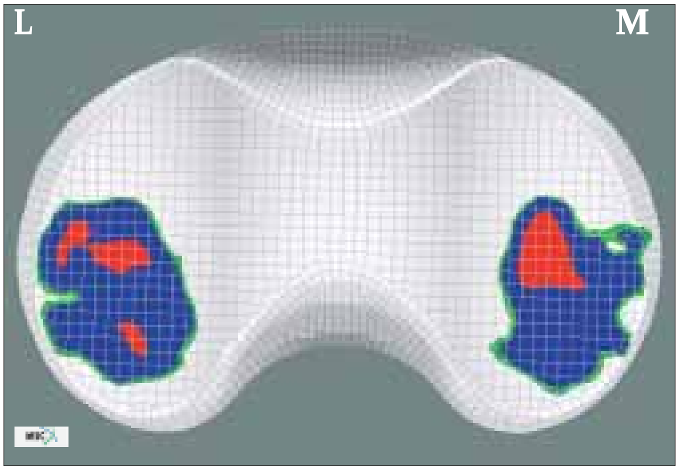
PFC Sigma RP Curved



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 381 mm^2

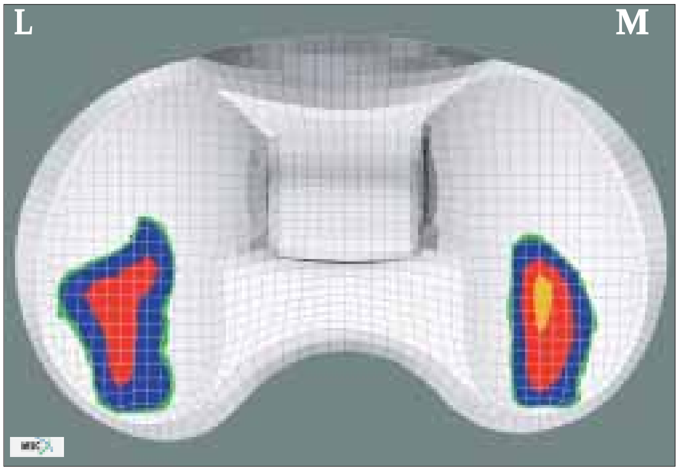


Midstance: 2.0 BW, 20° flexion
Contact Area: 398 mm^2

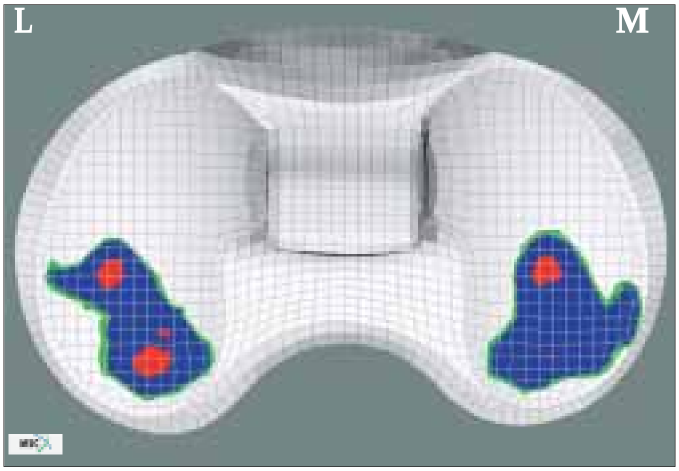


Toeoff: 3.0 BW, 15° flexion
Contact Area: 526 mm^2

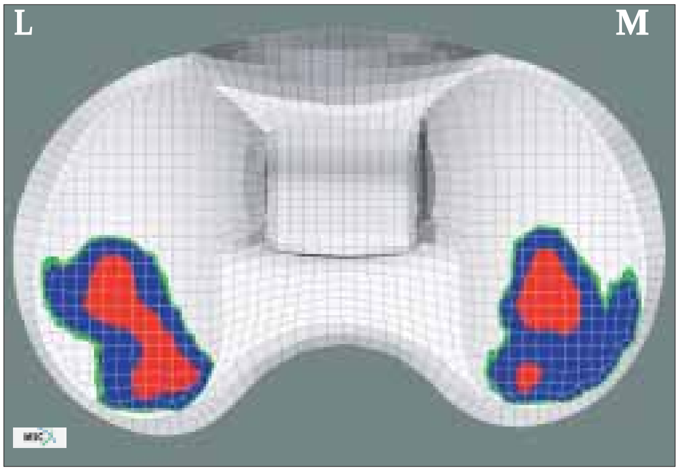
PFC Sigma RP Stabilized



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 326 mm^2



Midstance: 2.0 BW, 20° flexion
Contact Area: 356 mm^2



Toeoff: 3.0 BW, 15° flexion
Contact Area: 456 mm^2

DISCUSSION

Mobile bearing knee systems are emerging as an evolutionary advance in total knee design. They have demonstrated the ability to reduce stresses associated with abrasive damage but demand highly accurate and repeatable manufacturing. Although no precise equation exists that calculates the extent of abrasive wear as a function of contact stress,[3] experimental evidence[4] indicates that the higher the contact stresses the greater the propensity for abrasive damage. When conformity is achieved, the low contact stresses manifested in these systems can greatly attenuate abrasive wear debris generation. This finding is supported by laboratory wear simulation,[5] finite element models,[6] and long-term clinical usage[7,8,9] of the LCS Mobile Bearing Knee System. Similar stresses realized by the designs in this study suggest the prospect of comparable clinical longevity.

The femoral components for all systems evaluated are designed to function with both a mobile and fixed tibial plateau. The femoral component of each design has a variable sagittal curvature commonly referred to as a J-curve. The effect of the J-curve is evident in the change in contact pattern shapes for the Innex UCOR and the Interax knee designs in flexion. Its effect is more subtle in both PFC Sigma RP designs as they maintain a more consistent shape through the first twenty degrees of flexion. Regardless of the influence of the J-curve during walking gait, all four designs achieve lower stresses than fixed plateau designs.[10, 11]

CONCLUSIONS

The resulting contact stress distributions for all four mobile bearing knee systems evaluated suggest a minimal generation of abrasive wear debris when compared to contemporary fixed plateau knee designs. The greater conformity achieved by these designs contribute to their clinical longevity.

As mobile bearing knee designs continue to evolve, both pre-clinical and clinical assessments will determine their individual efficacy. Both clinicians and regulatory agencies should carefully monitor the increasing international use of these devices. The information presented should further assist manufacturers in ongoing design optimization required to assure the safety and effectiveness of these systems.[6,10,11,12,13,14]

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