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

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INTRODUCTION

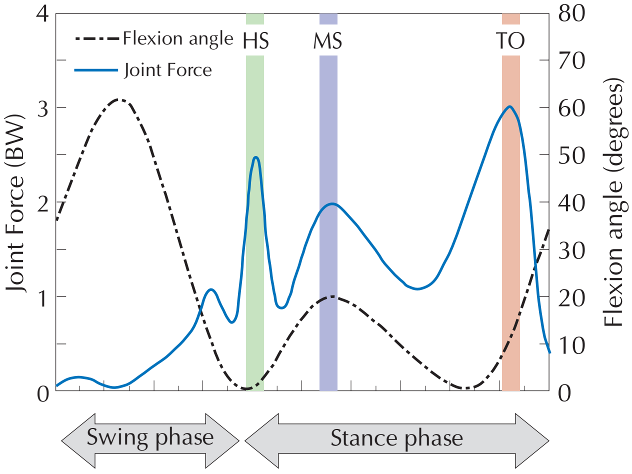
The abrasion observed in Ultrahigh Molecular Weight Polyethylene (UHMWPE) total knee arthroplasty component retrievals is the result of high cyclical loads, which act on the tibial plateau during daily ambulation. This dynamic process influences *in vivo* component longevity and is dependent on the magnitude and distribution of contact stresses on the tibial plateau. Mobile bearing knee systems offer the promise of 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 Dual Bearing Knee (Finsbury Orthopaedics Ltd.), e.motion (Aesculap AG & Co.KG), Gemini MKII Modular Knee System (Waldemar Link GmbH & Co.KG) and the Innex UCOR (Sulzer Orthopedics Ltd.). These systems are not currently available for clinical use in the United States.

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. The average loading conditions for the heelstrike, midstance and toeoff portions of the stance phase of the walking cycle were applied and the virtual components were allowed to settle into their preferred alignments without friction. All of the UHMWPE plateaus were characterized by a gamma irradiated, nonlinear material[1] 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.



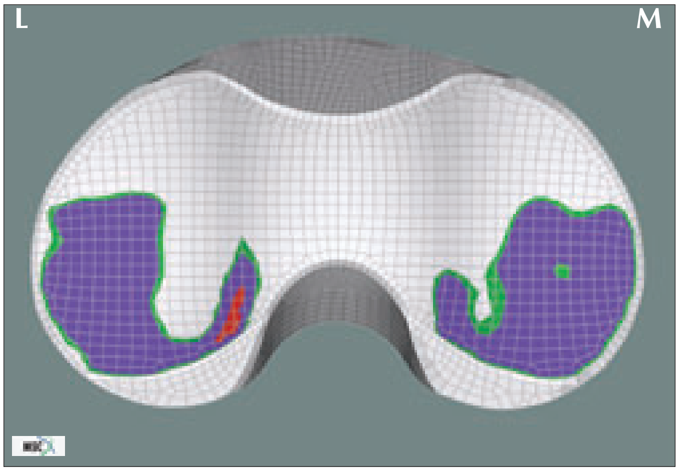
Walking Gait Cycle	Normal Joint Force	Knee Flexion Angle
Heelstrike	2.5 BW (1950 N)	0 degrees
Midstance	2.0 BW (1560 N)	20 degrees
Toeoff	3.0 BW (2340 N)	15 degrees

PROXIMAL CONTACT STRESS

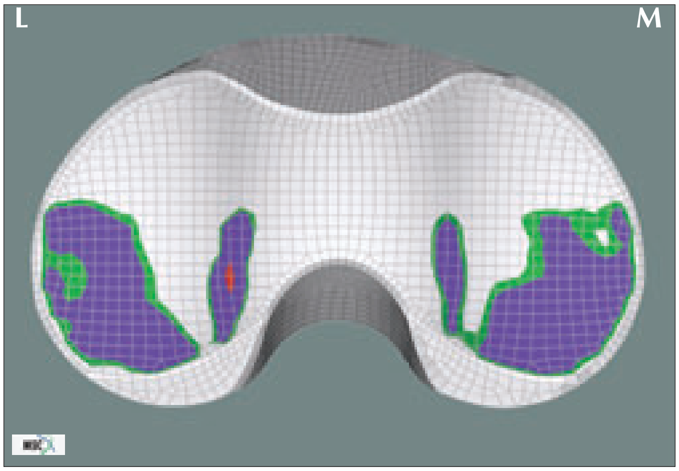
*1 MPa = 1 N/mm^2 = 145 psi

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

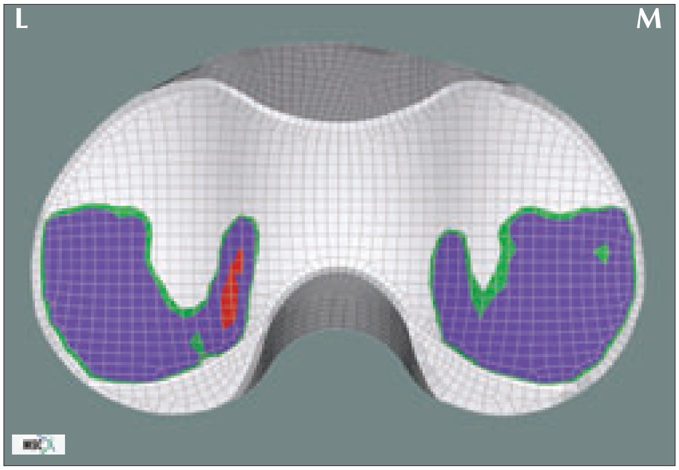
Dual Bearing Knee



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 595 mm^2

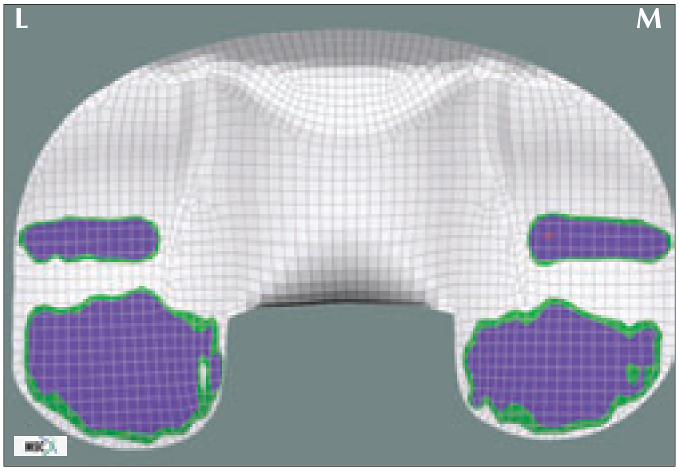


Midstance: 2.0 BW, 20° flexion
Contact Area: 558 mm^2

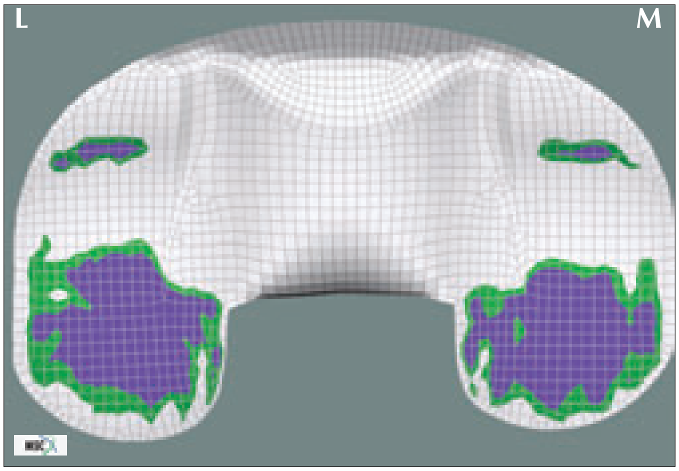


Toeoff: 3.0 BW, 15° flexion
Contact Area: 660 mm^2

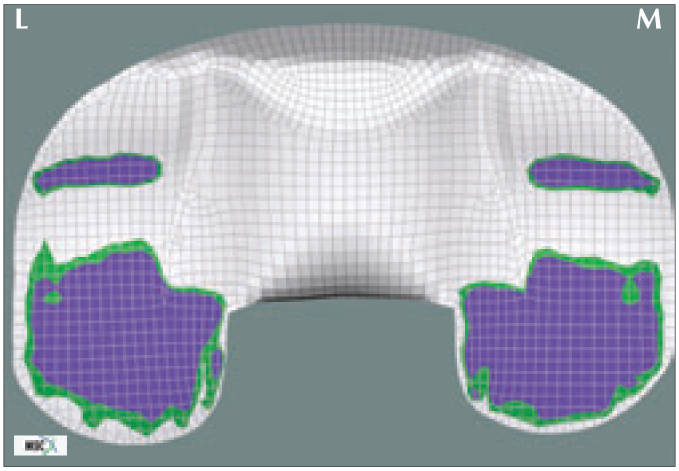
e.motion



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 666 mm^2



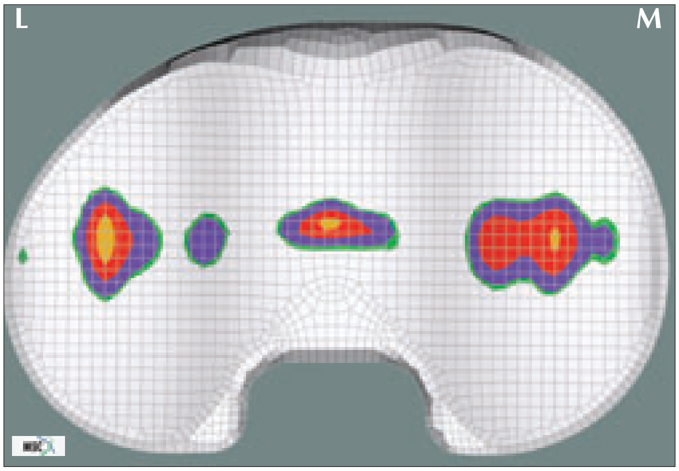
Midstance: 2.0 BW, 20° flexion
Contact Area: 659 mm^2



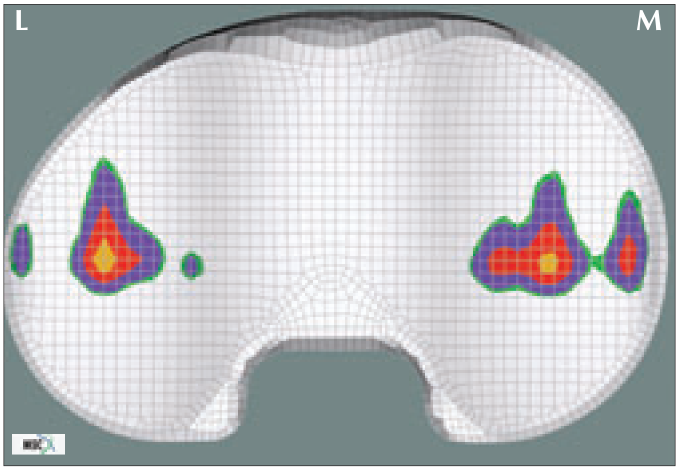
Toeoff: 3.0 BW, 15° flexion
Contact Area: 791 mm^2

femoral component can occur during the heelstrike, midstance 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. 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. Designs are presented in alphabetical order.

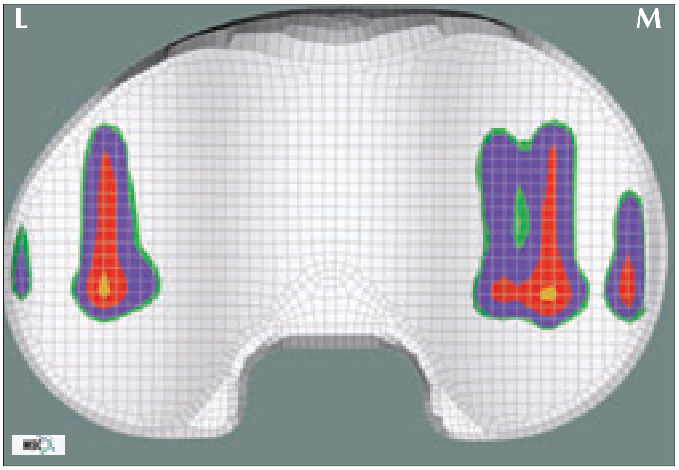
Gemini MKII



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 327 mm^2

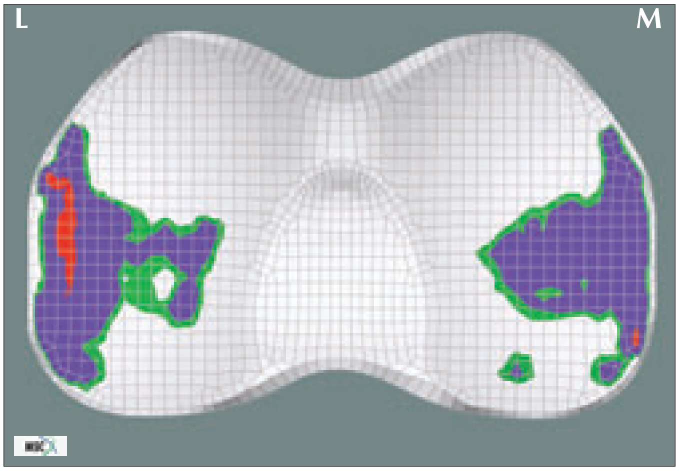


Midstance: 2.0 BW, 20° flexion
Contact Area: 305 mm^2

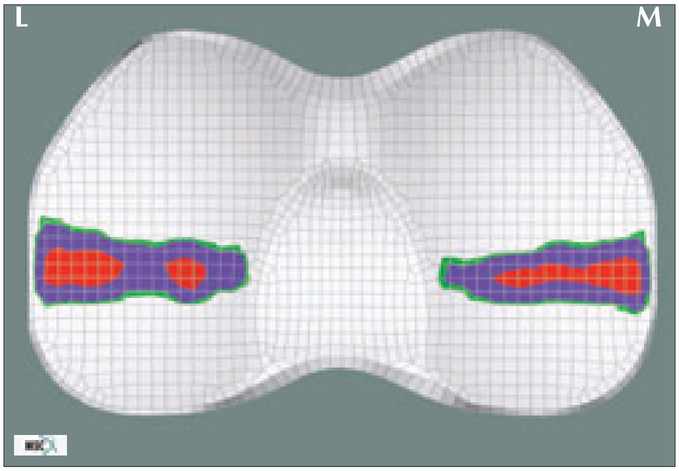


Toeoff: 3.0 BW, 15° flexion
Contact Area: 462 mm^2

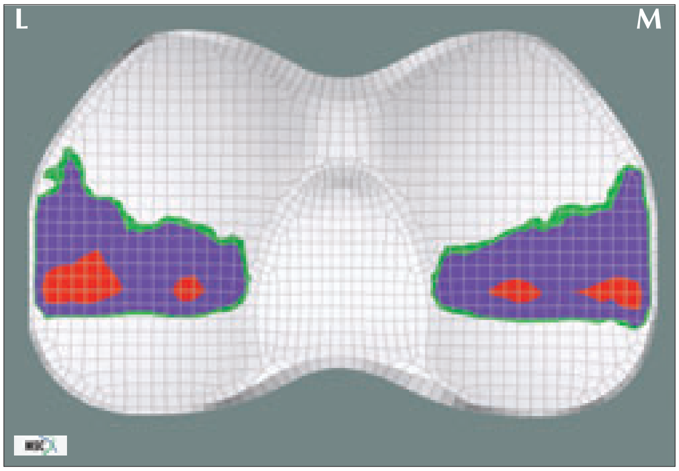
Innex UCOR



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

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 more accurate and repeatable manufacturing than required by less conforming fixed bearings. Although there is some controversy over the relationship of contact stress and area on the generation of wear debris,[2,3,4] no precise equation exists that predicts the extent of this interaction. Experimental evidence[5] suggests that the higher the contact stresses the greater the propensity for abrasive damage. When conformity is achieved, the low contact stresses realized in these systems reduce the potential for abrasive wear debris generation. This finding is supported by laboratory wear simulation,[6] finite element models,[7] and long-term clinical usage[8,9,10] of the LCS Mobile Bearing Knee System. Similar low stresses realized by designs in this study suggest the prospect of comparable clinical longevity.

Each system articulates differently through the stance phase of walking gait. For the flexion angles studied, the contact stress distributions of the Dual Bearing Knee and e.motion designs indicate a constant femoral component curvature with the contact stress patterns predominantly influenced by the magnitude of the applied loads. The changing sagittal curvature (J-curve) for the Gemini MKII, and more dramatically for the Innex UCOR, influences the resulting contact patterns and their location on the tibial plateau.

CONCLUSIONS

The Dual Bearing Knee and e.motion designs realize walking gait stress levels comparable to the clinical gold standard of mobile bearing knee design, the LCS.[7] The Innex UCOR performs similar to most mobile bearing knees studied by this laboratory[7,11] while the Gemini MKII results in contact stresses previously identified with fixed plateau systems.[12,13] The contact stress patterns achieved by the former three designs should 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 extends this laboratory's evaluations of mobile bearing knee designs and should assist manufacturers in ongoing design optimization required to assure the safety and effectiveness of these systems.

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