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

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INTRODUCTION

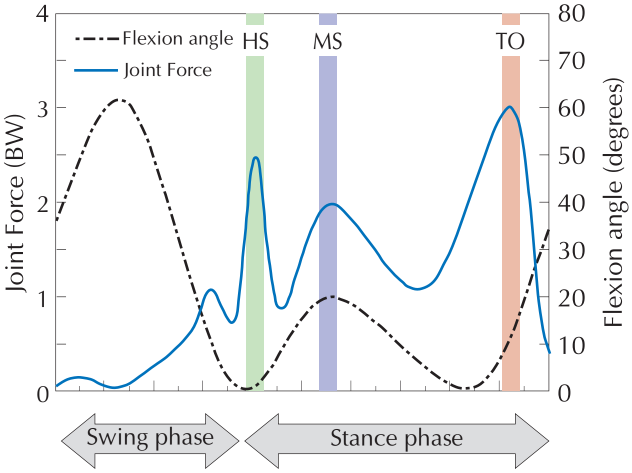
The abrasion observed in Ultrahigh Molecular Weight Polyethylene (UHMWPE) total knee arthroplasty component retrievals is the result of high cyclical loads, which act on the tibial plateau during daily ambulation. This dynamic process influences *in vivo* component longevity and is dependent on the magnitude and distribution of contact stresses on the tibial plateau. Mobile bearing knee systems offer 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 insert 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 LCS Rotating Platform (DePuy International, Ltd.), MBK (Zimmer, Inc.), Profix MBK (Smith + Nephew, Inc.) and SAL (Sulzer Orthopedics, Ltd.). Only the LCS Rotating Platform is currently available for clinical use in the United States, the others, however, represent 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 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. The UHMWPE inserts were characterized by a gamma irradiated, nonlinear material[2] of 10 mm thickness maintained at 37° Celsius. Contact areas and stresses on the tibial insert were calculated and their magnitudes and locations were then photorealistically imaged.



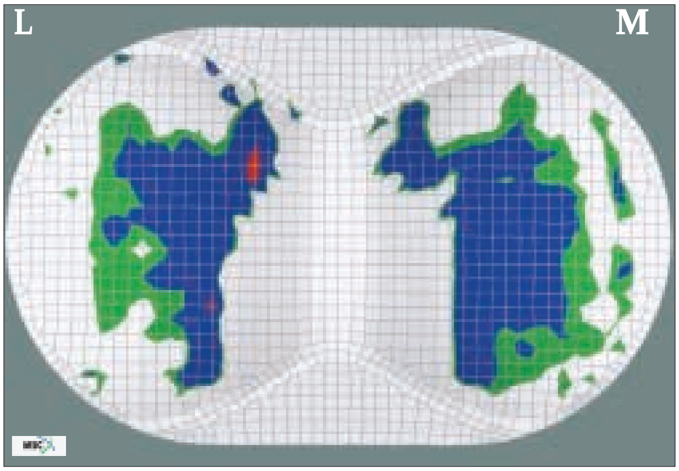
Walking Gait Cycle	Normal Joint Force	Knee Flexion Angle
Heelstrike	2.5 BW (1950 N)	0 degrees
Midstance	2.0 BW (1560 N)	20 degrees
Toeoff	3.0 BW (2540 N)	15 degrees

PROXIMAL CONTACT STRESS

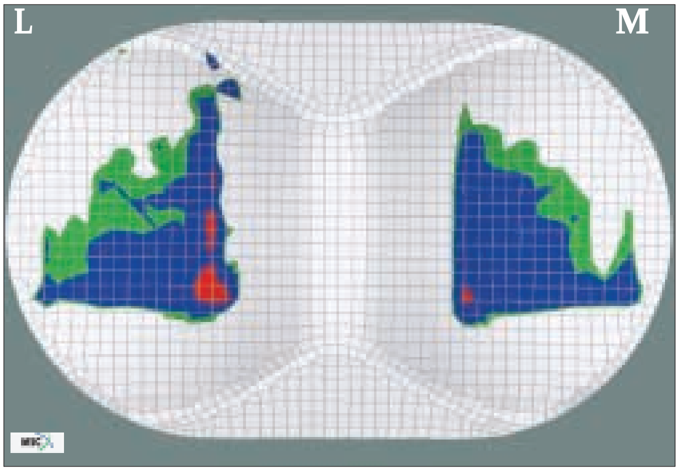
*1 MPa = 1 N/mm^2 = 145 psi

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

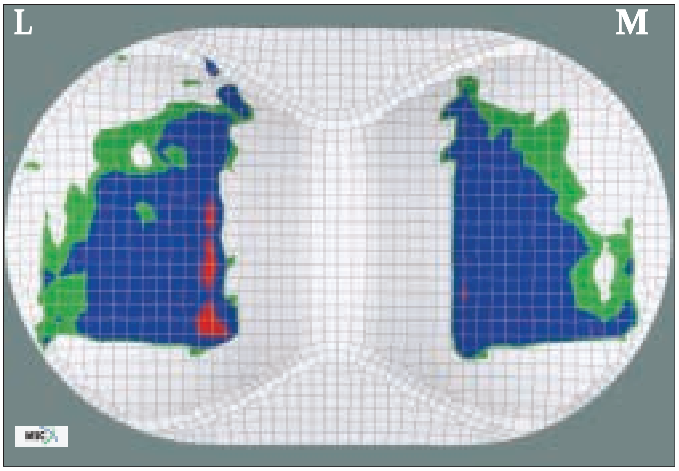
LCS Rotating Platform



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 875 mm^2

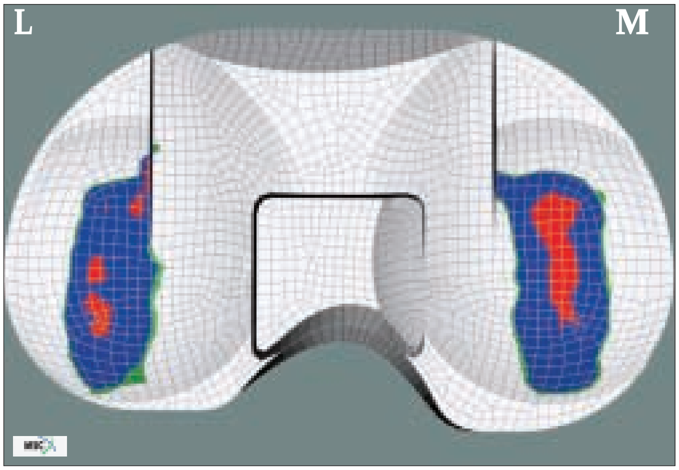


Midstance: 2.0 BW, 20° flexion
Contact Area: 615 mm^2

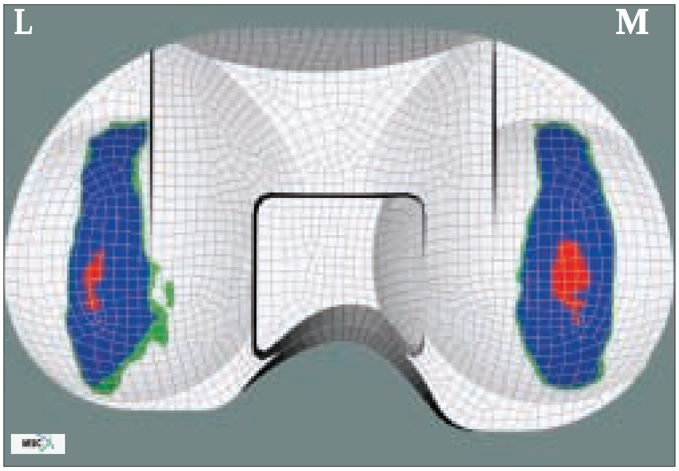


Toeoff: 3.0 BW, 15° flexion
Contact Area: 841 mm^2

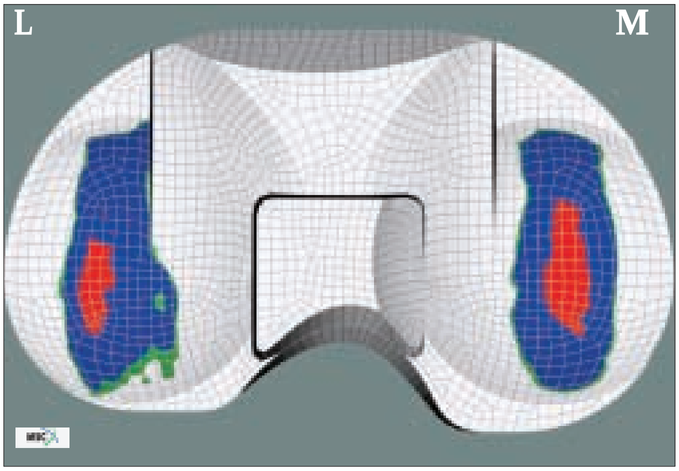
MBK



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 429 mm^2



Midstance: 2.0 BW, 20° flexion
Contact Area: 446 mm^2

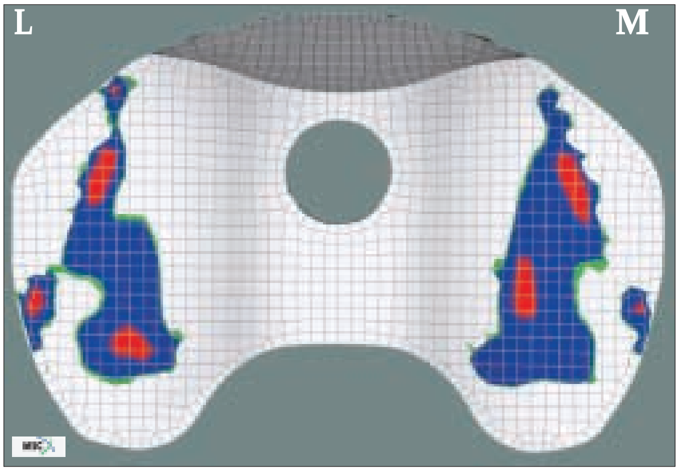


Toeoff: 3.0 BW, 15° flexion
Contact Area: 552 mm^2

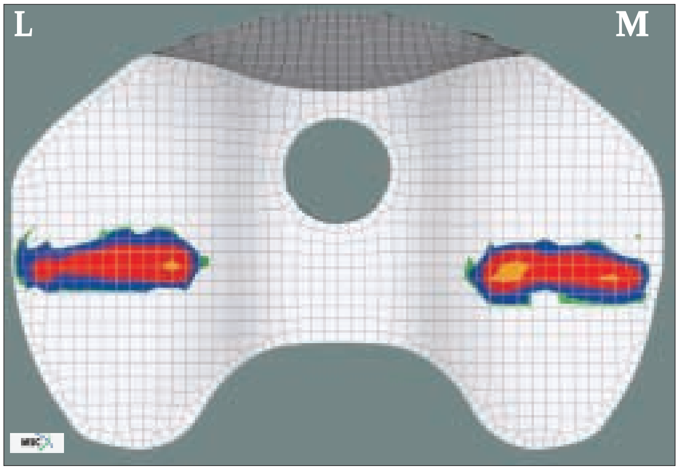
and toeoff positions. The higher the contact stresses the greater the propensity for abrasive damage. The proximal contact areas are determined using a 1 MPa threshold. Designs are presented in alphabetical order for each flexion angle.

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.

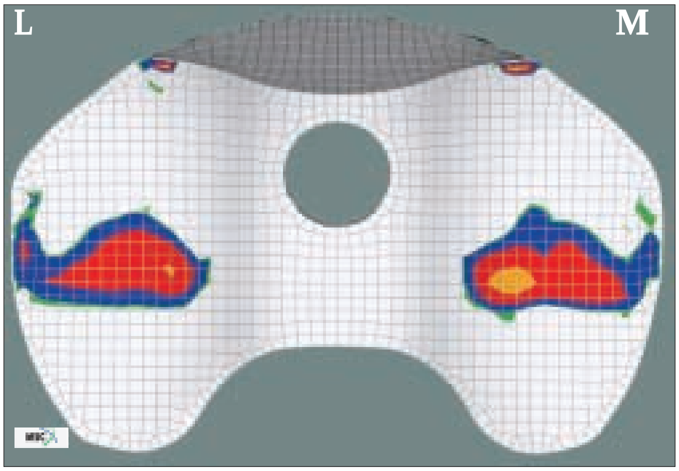
Profix MBK



Heelstrike: 2.5 BW, 0° flexion
Contact Area: 507 mm^2

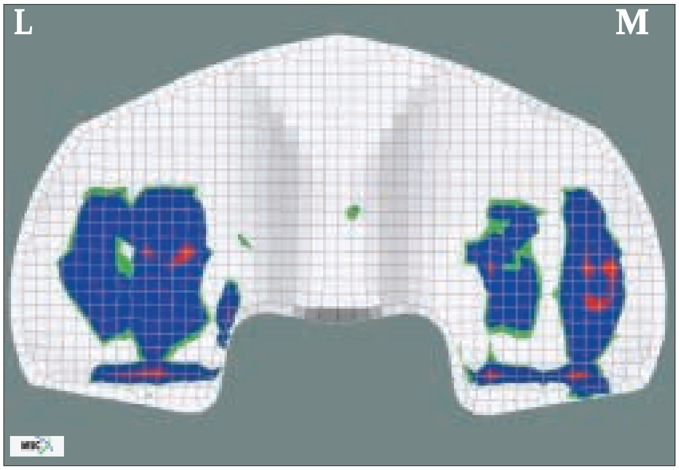


Midstance: 2.0 BW, 20° flexion
Contact Area: 237 mm^2

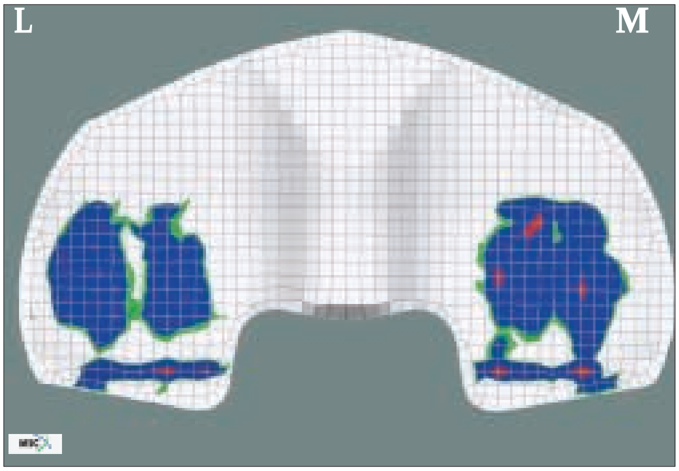


Toeoff: 3.0 BW, 15° flexion
Contact Area: 363 mm^2

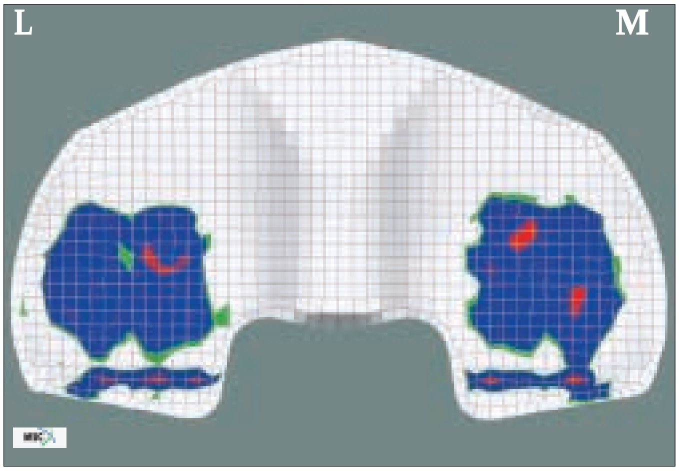
SAL



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



Midstance: 2.0 BW, 20° flexion
Contact Area: 476 mm^2



Toeoff: 3.0 BW, 15° flexion
Contact Area: 579 mm^2

DISCUSSION

Mobile bearing knee systems are emerging as an evolutionary advance in total knee design. This study suggests that when component conformity is achieved through precision manufacture, significantly reduced stresses are realized which will enhance polymer insert durability. 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 both simulator[5] and long-term clinical usage[6,7,8] of the LCS Mobile Bearing Knee System. Similar stresses realized in other designs in this study suggest the prospect of comparable clinical longevity.

All of the systems evaluated with the exception of the Profix MBK maintained a high degree of conformity throughout the stance phase of walking. The resulting contact stresses distributions for the LCS Rotating Platform, MBK, and SAL are some of the lowest measured for any knee system.[9,10,11,12,13] Although the Profix MBK demonstrates a loss of J-curve conformity in flexion, the contact stresses remain low when compared to fixed plateau designs.[9,10]

CONCLUSIONS

While three of the four designs maintained functionally equivalent stress distributions at the heelstrike, midstance, and toeoff positions, the fourth displayed a significant change in contact pattern. Although the magnitude of its contact stresses increased, they remained relatively low when compared to fixed plateau designs.

Mobile bearing knee replacements have demonstrated the ability to reduce stresses associated with abrasive damage but demand highly accurate and repeatable manufacturing. The contact stress levels determined for these four systems suggest minimal generation of abrasive wear debris volumes associated with the high cyclic loading of walking gait.

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.[9,10,11,12,13]

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