THE EFFECTS OF WALKING GAIT ON UHMWPE DAMAGE IN UNICOMPARTMENTAL KNEE SYSTEMS: A FINITE ELEMENT STUDY

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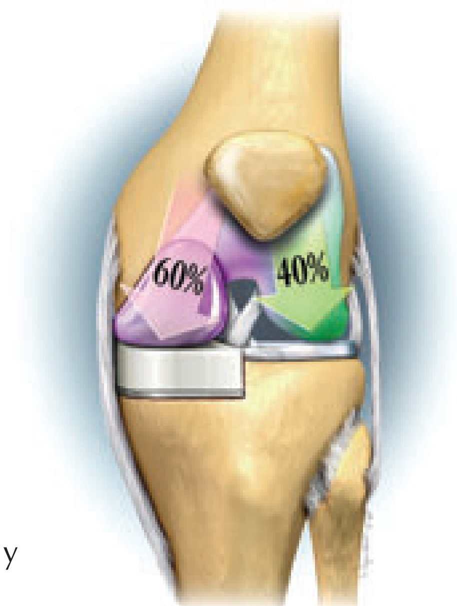
INTRODUCTION

There is increasing re-interest in the use of unicompartmental knee replacement as a remedy of choice for isolated compartment disease, although there is debate regarding its role as a temporizing or definitive procedure. The popularization of mini-incision surgery with claims of reduced pain, shorter hospitalization, more rapid rehabilitation, more normal knee function and decreased cost are positive arguments for the procedure. However, the damage observed in ultra-high molecular weight polyethylene (UHMWPE) component retrievals is the result of high cycle fatigue loads, which act on the polymer insert during daily ambulation and suggests a material limitation in their use.

This study reveals the influence that four different modular unicompartmental knee design geometries have on stresses that are associated with abrasion and delamination of the polymer insert and suggests their efficacy in clinical use. These designs include the Oxford Unicompartmental Phase 3 Mobile Bearing Knee (Biomet, Ltd), Advance Unicompartmental Knee (Wright Medical Technology), and the Preservation™ Uni-compartmental Fixed Bearing and Mobile Bearing Knees (DePuy, a Johnson & Johnson Company). The latter three designs have been recently introduced for use in the United States, while the Oxford has reported successful long-term clinical experience in Europe[1,2].

METHODS

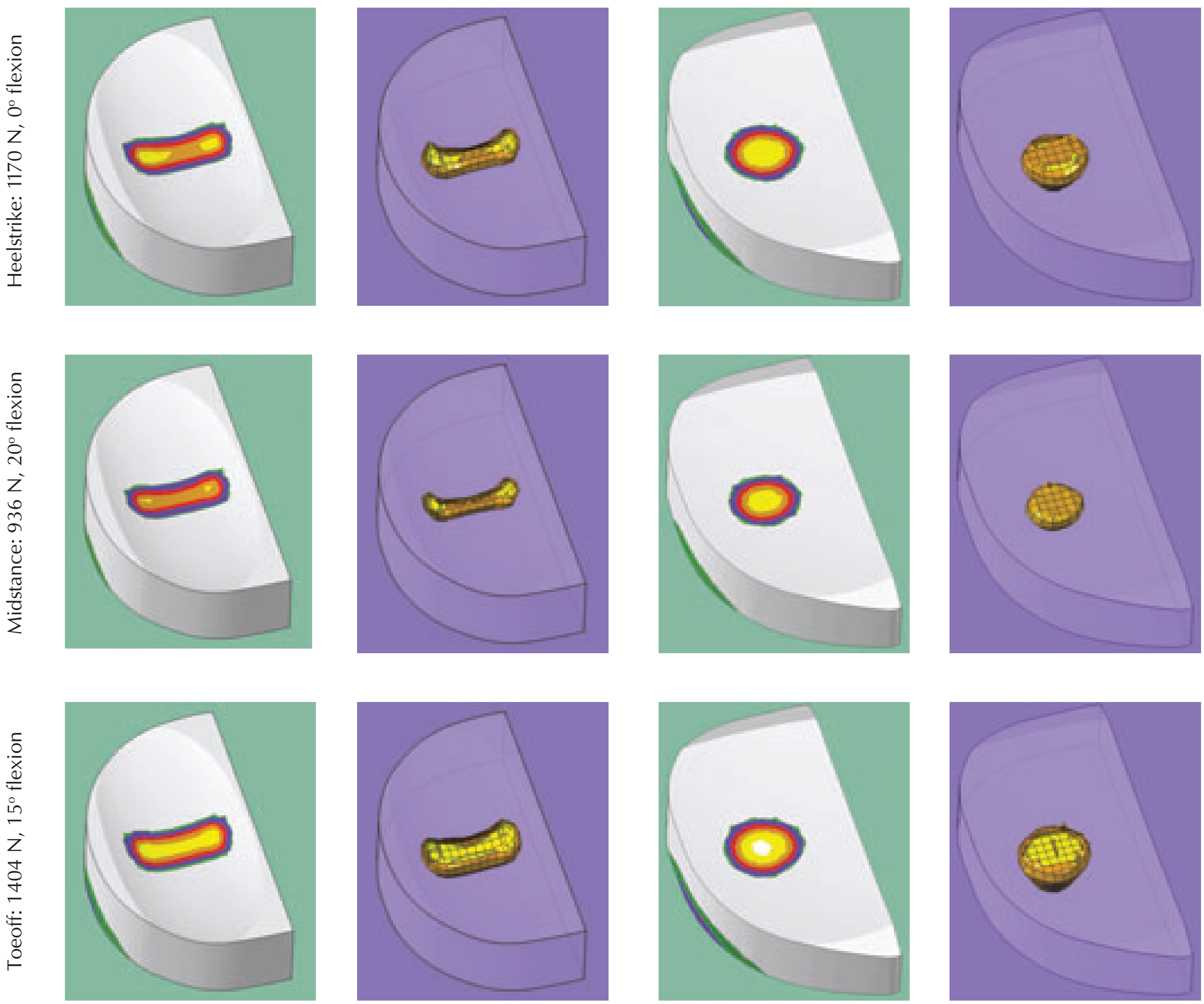
A three-dimensional, finite element model was created for each unicompartmental knee design by measuring the articular surfaces of implantable quality parts using a point laser profilometer. Surgical procedure was followed when positioning components in the medial compartment of the virtual left knee. The three most highly loaded positions in the walking gait cycle, heelstrike (0° flexion, 1,950 N), midstance (20° flexion, 1,560 N) and toeoff (15° flexion, 2,340 N), were simulated with the medial compartment receiving 60% of these loads[3]. All of the UHMWPE inserts were characterized by a gamma irradiated, nonlinear material[4] of 10 mm thickness maintained at 37° Celsius. Stresses associated with abrasion (Compressive Normal) and delamination (Von Mises) were calculated and their magnitudes and locations imaged photorealistically allowing visual comparisons for each loading condition.



RESULTS These images are appreciated from a superior anterior view of the medial compartment of the left knee for the three most highly loaded portions of the walking gait cycle: heelstrike, midstance and toeoff. The components are optimally aligned for these positions with the fixed plateau systems shown on the left, mobile bearing systems on the right.

Contact stress images give an indication of areas where surface abrasion caused by contact with the femoral component can occur. The higher the contact stresses the greater the propensity for abrasive damage. Von Mises isosurface stress images illustrate volumes of polymer within the insert stressed above a 9 MPa damage threshold[5]. Isosurfaces are defined by points of identical stress magnitude, and when present, appear as

Advance Unicompartmental		Preservation™ Fixed Bearing	
Contact Stress	Von Mises Stress	Contact Stress	Von Mises Stress

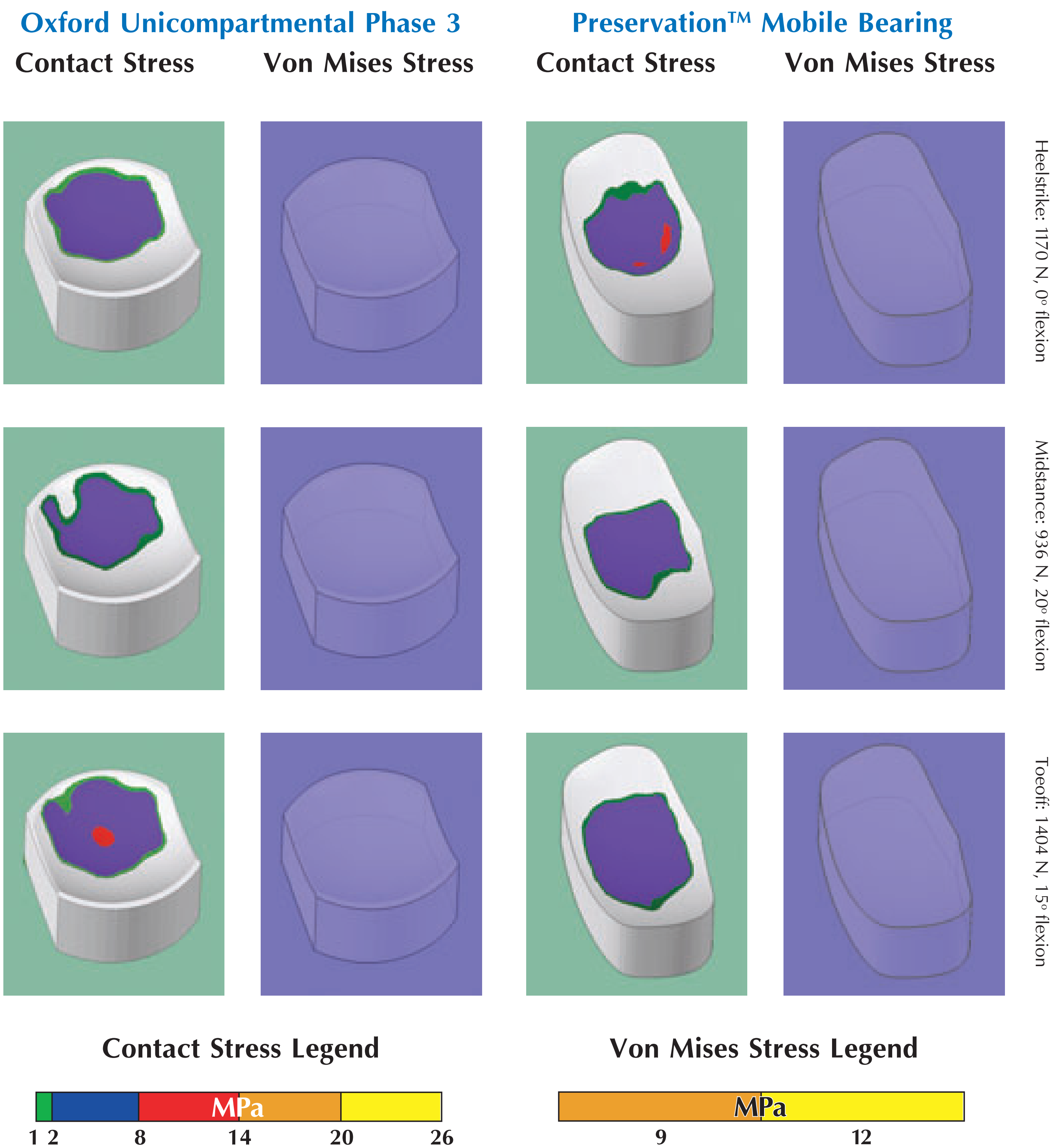


Contact Stress Legend

Von Mises Stress Legend

concentric spheroids or cylinders. These volumes indicate locations where shear cracks may initiate and propagate parallel to, but just below, the articulating surface. Contact areas were calculated with a 1 MPa threshold and are summarized in the table below:

Contact Areas (mm^2)	Advance Unicompartmental Knee	Preservation™ Uni-compartmental Fixed Bearing Knee	Oxford Unicompartmental Knee Phase 3	Preservation™ Uni-compartmental Mobile Bearing Knee
Heelstrike	112	99	328	266
Midstance	108	86	284	291
Toeoff	121	113	346	371



DISCUSSION

The four designs in this study clearly fall into two classes of conformity. The Advance and Preservation™ Unicompartmental Fixed Bearing designs are examples of less conforming geometries typically found in fixed plateau total knee systems. Their contact and Von Mises stress results are comparable to the Duracon, NexGen, and Foundation Total Knee systems that were evaluated using a similar testing protocol[6,7]. The Oxford Phase 3 and Preservation™ Unicompartmental Mobile Bearing designs are more conforming, as they exhibit very low contact stress and an absence of Von Mises stress above the material damage threshold of 9 MPa. When compared to tri-compartmental, mobile bearing knee systems[8,9,10] using a similar testing protocol, these two unicompartmental designs performed as well or better than most.

CONCLUSIONS

Stresses associated with abrasive and delamination wear debris generation are very low for the Oxford Unicompartmental Phase 3 and Preservation™ Mobile Bearing designs. The greater conformity imparted by these designs is a positive contribution to extending their clinical longevity. While the stress results for the Advance Unicompartmental and the Preservation™ Fixed Bearing designs are less favorable than the above, their results are comparable to several clinically successful, fixed bearing, tri-compartmental systems.

However, it must be appreciated that regardless of design geometry, successful unicompartmental knee replacement is highly dependent upon careful patient selection with regards to habitus and soft tissue competency as well as component placement.

As unicompartmental knee designs continue to evolve, pre-clinical and clinical assessments will determine their individual efficacy. Both clinicians and regulatory agencies should carefully monitor the increasing worldwide 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.

REFERENCES

1. Murray, D. W., Goodfellow, J. W., O 'Connor, J. J., "The Oxford medial unicompartmental arthroplasty: a ten-year survival study", Journal of Bone and Joint Surgery (British), 80(6):983-9, 1998.
2. Lidgren, L., "Annual Report 2001 - Swedish Knee Arthroplasty Register - Part 1", http://www.ort.lu.se/knee/pdf/skar2001eng.pdf, 2001.
3. Daley, R. E., "Measurement of the Distribution of Forces at the Human Knee Joint", Ohio State University Ph.D. Thesis 75-19,426, 1975.
4. Waldman, S. D., Bryant, J. T., "Compressive Stress Relaxation Behavior of Irradiated Ultra-High Molecular Weight Polyethylene at 37° C", Journal of Applied Biomaterials, Vol. 5, 333-338, 1994.
5. Williams, J. G., Stress Analysis of Polymers, Halstead Press, John Wiley & Sons, 1984.

6*. Morra, E. A., Postak, P. D., Greenwald, A. S., "The Effects of Articular Geometry on Delamination and Pitting of UHMWPE Tibial Inserts: A Finite Element Study", Orthopaedic Transactions, 20:66, 1996.

7*. Morra, E. A., Postak, P. D., Greenwald, A. S., "The Effects of Articular Geometry on Delamination and Pitting of UHMWPE Tibial Inserts II: A Finite Element Study", Orthopaedic Transactions, 21:217, 1997.

8*. Morra, E. A., Postak, P. D., Greenwald, A. S., "The Influence of Mobile Bearing Knee Geometry on the Wear of UHMWPE Tibial Inserts III: A Finite Element Study", Proceedings of the American Academy of Orthopaedic Surgeons Annual Meeting, 1:617, 2000.

9*. Morra, E. A., Postak, P. D., Greenwald, A. S., "Tibial Plateau Abrasion in Mobile Bearing Knee Systems During Walking Gait: A Finite Element Study", Proceedings of the American Academy of Orthopaedic Surgeons Annual Meeting, 2:660, 2001.

10*. Morra, E. A., Postak, P. D., Heim, C. S., Greenwald, A. S., "Tibial Plateau Abrasion in Mobile Bearing Knee Systems During Walking Gait II: A Finite Element Study", Proceedings of the American Academy of Orthopaedic Surgeons Annual Meeting, 3:740, 2002.

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