PATELLO-FEMORAL REPLACEMENT POLYMER STRESS DURING DAILY ACTIVITIES: A FINITE ELEMENT STUDY

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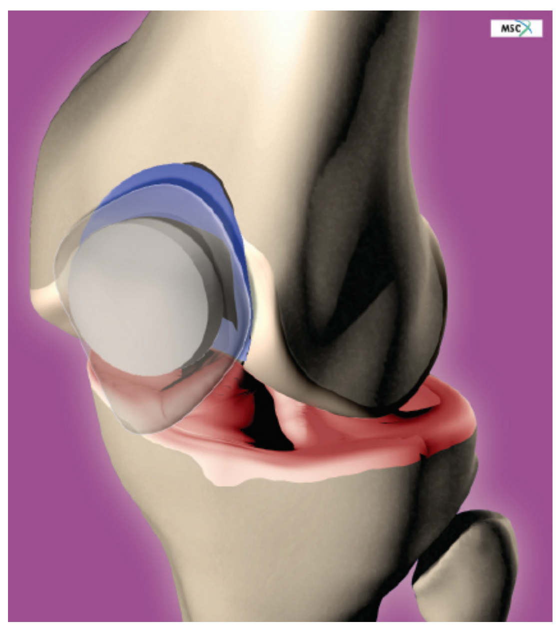
INTRODUCTION

Isolated, symptomatic patello-femoral arthritis, although uncommon, has been reported[9] to affect 8% of women and 2% of men over the age of 55. Both conservative and surgical non-arthroplasty interventions have been advocated[7], however, their reports suggest limited success. Patello-femoral replacement designs as a solution alternative are beginning to re-emerge largely through an appreciation of design requirements and the importance of component placement, which have been major factors in earlier clinical disappointments.[1,3,6]

This study reveals the influence that three different patello-femoral implant design geometries have on stresses that are associated with polymer abrasion and delamination and suggests their efficacy in clinical use. These designs include the LCS PFJ (DePuy, a Johnson & Johnson Company), Vanguard (Biomet, Ltd) and Scout (Waldemar Link GmbH). The former two designs are available for clinical use in the United States.

METHODS

Geometries for a three-dimensional, finite element model of each patello-femoral design were created by measuring the articular surfaces of implantable quality parts using a point laser profilometer. Surgical procedure was followed when positioning the components into a virtual left knee. The results of a kinematic analysis of a generic total knee replacement[5] were used to define the relative position of the trochlear component with the patellar component at three knee flexion angles that occur during daily activity. Applied patella joint loads for each activity were determined from the literature.[4,8] The patellar component was allowed to settle into its preferred alignment as if constrained by the patellar tendon and ligament. To aid in comparison, all polymer patellar components were characterized by the same gamma irradiated, nonlinear material[10] of 10 mm maximum thickness. Stresses associated with abrasion (Compressive Normal) and delamination (Von Mises) were calculated and their magnitudes and locations imaged photorealistically.



RESULTS

The stress distributions of the patellar components are appreciated from a posterior view of the left knee for three common daily activities: walking (toe off position), stair ascent and chair rise. Contact stress images (green background) give an indication of areas where surface abrasion caused by contact with the trochlear component can occur. The higher the contact stresses the greater the propensity for abrasive damage.

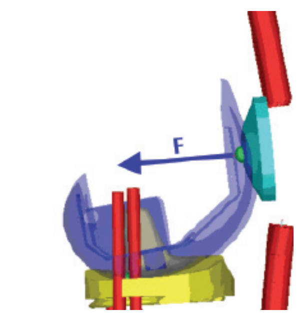
Von Mises isosurface stress images (purple background) illustrate volumes of polymer within the insert stressed above a 9 MPa damage threshold.[11] Isosurfaces are defined by points of identical stress magnitude, and when present, appear as concentric spheroids or cylinders. These volumes indicate locations where shear cracks may initiate and propagate parallel to, but just below, the articulating surface. Designs are presented in alphabetical order. Contact areas were calculated with a 1 MPa threshold and are summarized in the following table:

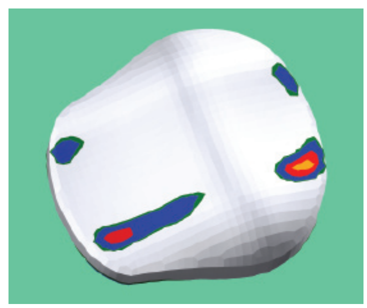
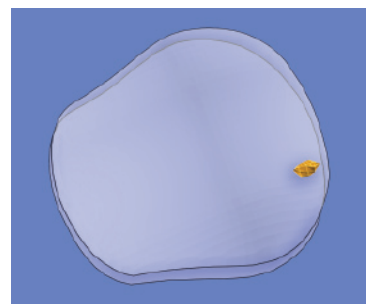
KneeSim Kinematic Model

LCS PFJ

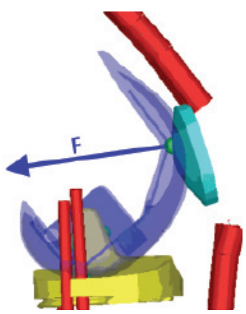
Contact Stress | **Von Mises Stress**

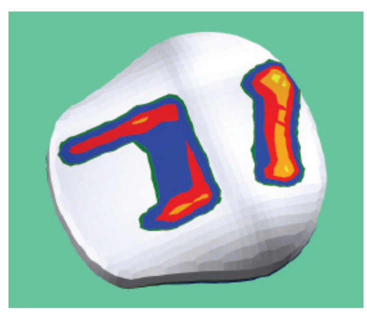
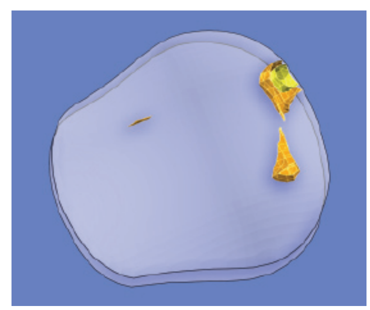
Walking Gait
15° Flexion
F = 420 Newtons



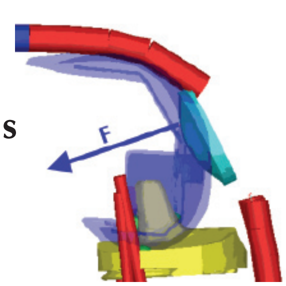



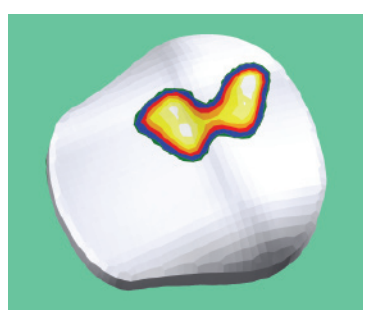
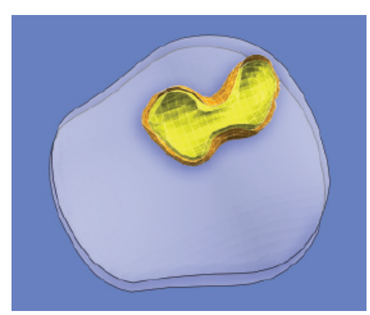
Stair Ascent
45° Flexion
F = 1760 Newtons



Chair Rise
90° Flexion
F = 1950 Newtons



Contact Area (mm²)	LCS PFJ	Scout	Vanguard
15 degrees	96	80	42
45 degrees	269	148	97
90 degrees	132	162	100

Contact Stress

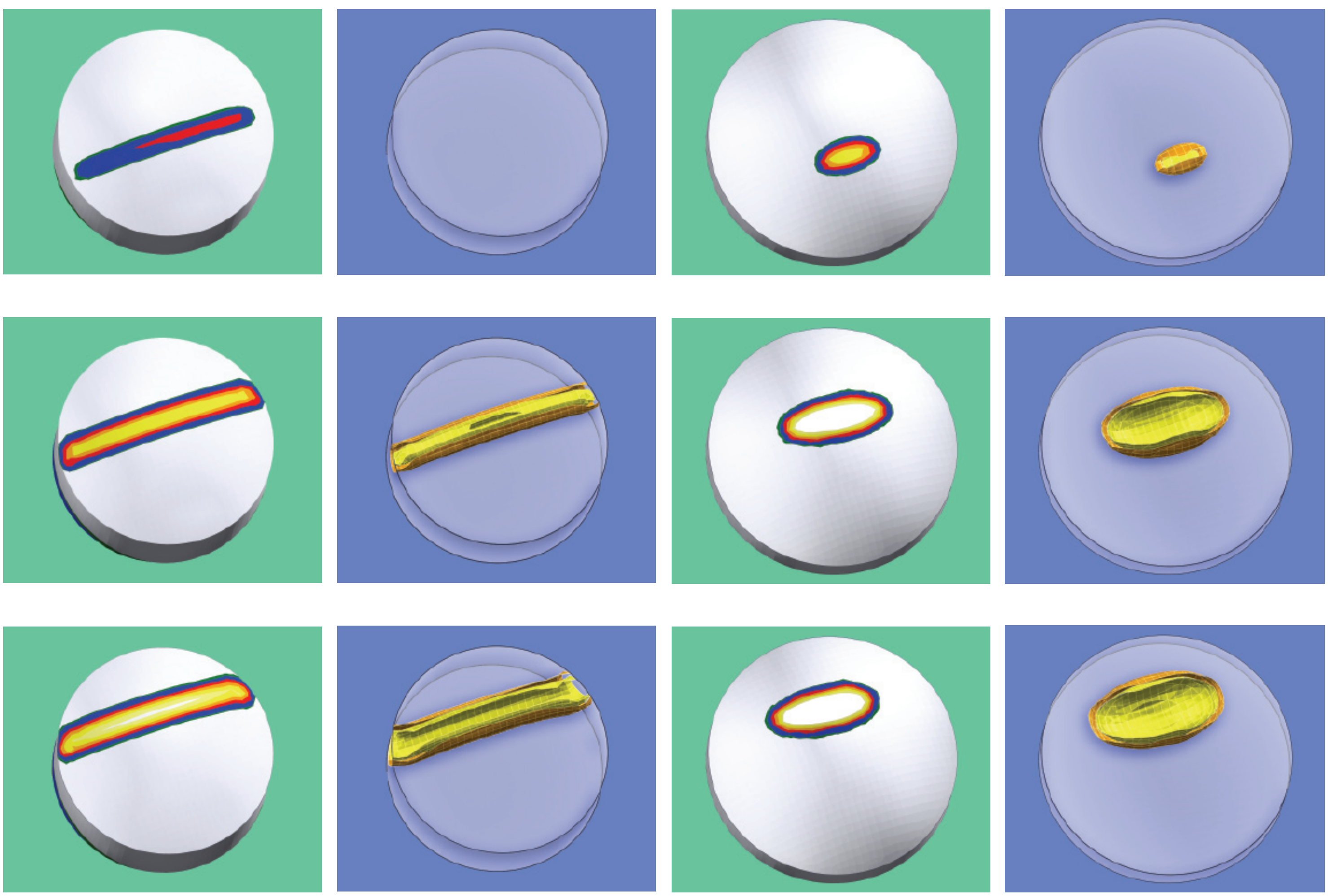
*1 MPa = 1 N/mm = 145 psi

Von Mises Stress

Scout

Vanguard

Contact Stress | **Von Mises Stress** | **Contact Stress** | **Von Mises Stress**



DISCUSSION

The kinematic model of the generic total knee replacement indicated that patello-femoral contact at 15° of knee flexion occurs slightly inferior to the midline of the patellar component and progresses superiorly as flexion increases. This is in agreement with the literature on the natural patella.[2] The patella initiates contact with the trochlear component at 15° of flexion, the toeoff portion of walking gait, where the joint loads are relatively low. As flexion progresses through stair ascent and chair rise, the combined actions of the quadriceps mechanism and to a lesser degree the collateral ligaments, contribute to significantly increasing resultant compressive loading.

The LCS PFJ trochlear component has a sulcus that tends to confine the contact area. Contact favors the inferior side at 15° flexion, the middle at 45° flexion where contact area is largest and the superior side at 90° flexion. Von Mises stresses arise beneath areas of contact where there is a rapid change in contact stress.

The Scout has a relatively low rise dome geometry and when coupled with a broader trochlear groove, demonstrates line contact across all of the positions studied. The rapid change in contact stress in the superior direction during stair ascent and chair rise leads to a cylindrical volume of polymer with Von Mises stresses above 9 MPa.

The Vanguard exhibits classic Hertzian focal contact and Von Mises stress distributions for all three activities. This may result in a flattening of polymer geometry through permanent plastic deformation at these high stress locations. This could be of benefit in reducing stress by increasing component conformity during clinical use but may do so at the expense of altered kinematics.

EPILOGUE

There is a resurgence of interest in patello-femoral arthroplasty for isolated compartmental arthritis.[3,6] Contemporary designs should display an appreciation of a broader trochlear groove to maximize congruent patellar component contact through the flexion/extension range of motion, which seeks to minimize surface and subsurface stresses. These designs must be accompanied by instrumentation designed to ensure alignment, resisting dislocation. The essential features of these designs are to minimally alter articulation mechanics of the lateral/medial compartments through the flexion/extension range. The components evaluated are representative of this design class, and their current clinical use is short-term and should be followed purposefully.

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