WEAR OF UHMWPE COMPONENTS OF TOTAL KNEE REPLACEMENTS DEPEND UPON WALKING PATTERN

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INTRODUCTION:
TKR subjects often demonstrate abnormal gait patterns (75% according to Andriacchi et al. (1)), which are likely to impact wear of the ultra-high molecular weight polyethylene (UHMWPE) tibial component. It has been shown that walking following TKR produces large cyclic variations in normal and tangential forces as well as movement of these forces along the tibial articulating surface (2). The purpose of this study was to compare the stress variations in a UHMWPE component of a TKR associated with the varying load (position and magnitude) that occurs during each gait cycle for two different gait patterns, a normal walking pattern as well as for a quad-avoidance walking pattern. It is hypothesized that the stress variations and hence the associated wear distributions will be different for normal walking pattern and quad-avoidance walking pattern.

MATERIALS AND METHODS:
A three-dimensional finite element analysis using commercially available software ADINA was performed in order to evaluate the stress distribution within the tibial component. The loading at the knee joint, used as input for the stress analysis, was estimated by the use of a model of the knee (2). Among other inputs, gait measurements of patients with total knee replacements were used in the knee model. The medial half of a Miller/Galante UHMWPE tibial component of the prosthesis was modeled. Non-linear material properties of UHMWPE were taken from literature (3). The femoral component was modeled with Co-Cr alloy elastic material properties. The placement of the polyethylene component on a metal tray was simulated in the model. The movement of the femoral component over the tibial insert was modeled using prescribed displacements of the femoral component. The normal load as well as the tangential load, which varied with the location, was dragged along the tibial surface. Stresses in the polyethylene component (compressive contact stress, tensile tangential stress and shear stress) during a gait cycle were obtained for both normal and quad-avoidance gait patterns.

RESULTS:
Contact induced compressive stress in the UHMWPE under both normal walking load pattern as well as under quad-avoidance walking pattern followed the load distribution closely (Figure 1). Maximum compressive stress of 33 MPa occurred at the posterior region of the tibial insert for a normal walking pattern while a stress of similar magnitude occurred at the anterior region of the implant when the quad-avoidance pattern was considered (Figure 2). Maximum tensile tangential stress near the surface (3.0 MPa) as well as maximum shear inside the component (4.8 MPa) occurred in the posterior region for a normal walking pattern while similar maximum (2.5 MPa and 4.3 MPa) occurred in the anterior region for quad-avoidance walking pattern.

In each gait cycle, normal walking pattern showed cyclic stress variations in the posterior region of the implant. Contact induced compressive stresses varied from 22.0 MPa to 33.0 MPa, maximum shear stress ranged between 2.8 MPa and 4.8 MPa and tensile tangential stress varied between 1.0 MPa and 3.0 MPa. Cyclic variation in stresses also occurred for quad-avoidance walking pattern during each gait cycle but was located in the mid-region of the tibial implant: 25.0 MPa to 30.0 MPa of contact induced compressive stress, 3.0 MPa to 3.6 MPa maximum shear stress and 1.5 MPa to 1.7 MPa of tensile tangential stress.

DISCUSSION & CONCLUSIONS:
This study showed that stress levels in polyethylene were comparable for the normal and quad-avoidance gait pattern but occurred at different locations of the implant. Normal walking produced maximum compressive stress at the posterior region of the implant suggesting possible creep deformation in the posterior region. This walking pattern also induced magnitude changes in both maximum shear stress and tensile tangential stress in the posterior region of the implant indicating possible crack initiation in the presence of subsurface defects and delamination. Quad-avoidance walking introduced maximum contact compressive stress over the anterior region of the implant suggesting creep deformation in that region. Cyclic variations in maximum shear and tensile tangential stresses also occurred in the mid-region of the implant for the quad-avoidance walking pattern, indicating possible crack initiation and delamination in the mid-region of the implant.

The current stress analysis, even though has not included material defects in the model, is consistent with the potential for several modes of wear including surface deformation, surface and subsurface cracking, and delamination. It should be noted, however, that with the exception of surface deformation, the cyclic fatigue wear is dependent on the presence of material defects, which act as a point of stress concentration.

The current analyses showed that possible failure locations do depend on the walking pattern of the subject. This observation is consistent with a recent retrieval study, which demonstrated a close relationship between wear scar formation and the host’s gait pattern (4). Creep deformation of the UHMWPE is possible in the posterior region of the implant for normal walking subjects while permanent deformation might occur in the anterior region for subjects with quad-avoidance walking pattern. Also, the other types of failure mechanism such as cracks and delamination might occur in the posterior region for a normal walking pattern while such failure, even though may be less likely, might occur in the mid region of the implant for quad-avoidance pattern of walking.

In summary, gait variations appear to impact wear of TKR tibial components and should be further analyzed.

CITED LITERATURE

Figure 1. Stress distribution for normal walking pattern

Figure 2. Stress distribution for quad-avoidance walking pattern