THE EFFECTS OF HIP CONTACT
ABERRATIONS ON STRESS PATTERNS
WITHIN THE HUMAN FEMORAL HEAD

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A two-dimensional finite element model incorporating cancellous bone
inhomogeneity is used to study femoral head stress alterations caused by changes
from the usual articular contact patterns. The contact stress distributions,
calculated from an earlier mathematical analysis by Greenwald and O'Connor
(16), are found to influence not only the adjacent subchondral bone, but rela-
tively distant parts of the head as well. Both abnormally large joint incongruity
and abnormally low cartilage compliance cause load to shift away from the
superior "weight-bearing" area, out toward the periphery of the contact region.
As a consequence, transverse compressive stresses, which are of appreciable
magnitude but which do not contribute to weight bearing, are built up through-
out much of the superior and central portions of the femoral head. Most small
changes in the overall cartilage thickness or in its thickness distribution, when
considered in isolation from hip compliance changes, have only minor effects on
the internal stress distribution. An important exception is cartilage thinning at
the superior margin, which can result in abrupt longitudinal compressive stress
concentrations. It is suggested that such alterations of the normal patterns of
stress transmission may contribute to sclerosis or to the formation of osteo-
phytes or cysts in the osteoarthritic hip.

The long-term integrity of the human femoral head as a weight-bearing
organ is often subject to compromise by degenerative changes, particularly
those of osteoarthritis. Aberrant patterns of articular surface loading clearly
affect the mechanical stress state in the underlying articular cartilage and
subchondral bone (24). Interestingly, both abnormally high (13) and ab-
normally low (7) stress levels have been implicated in the pathogenesis of osteoarthritis. But the extent to which contact stress pattern alterations influence the stress field within the femoral head as a whole is not well understood. An appreciation of this relationship may prove important, because the complex patterns of trabeculation will be altered to accommodate an abnormal stress state. And, since local regions of high elastic modulus within an epiphyseal region have been shown to transmit elevated stresses (3), the initial aberrant contact stress patterns may become self-sustaining. In the present study, a two-dimensional inhomogeneous finite-element model is used to evaluate the stress distribution changes within the femoral head resulting from a series of perturbations in the articular contact stress. The stress perturbations arise from variations (1) in the total hip loading, (2) in the degree of incongruity in the non-weight-bearing hip, (3) in the minimum cartilage thickness, (4) in the distribution of cartilage thickness, and (5) in the overall femoral head deformation under load.

Bullough et al. (6,7), and Greenwald and associates (14,15,16) have conducted extensive studies of contact areas in the human hip, using injected dye to stain cartilage in the noncontact areas. Their results clearly demonstrate that the femoral head cartilage underlying the dome of the acetabulum of a normal hip comes into contact only during the high-force portions of the loading cycle. By contrast, cartilage underlying the periphery of the acetabulum is habitually in contact. These phenomena are consistent with observations showing that the radius of curvature of the (somewhat aspherical) acetabulum is slightly smaller than that of the (very nearly spherical) femoral head (2). Interestingly, Bullough et al. (6) have found that the asphericity of the acetabulum decreases significantly with increasing age. Measurements by P.S. Walker et al. (33) have shown that the maximal subdome gap in the normal unloaded young adult hip is only 0.5 mm, suggesting that the geometrical tolerances affecting hip mechanics are small indeed.

To date, there have been only indirect measurements of the distribution of articular contact stresses in the natural hip (9), although ultraminiature piezoresistive transducers suitable for direct measurements have been recently developed (5). Greenwald and O'Connor (16), however, have presented a simplified mathematical contact stress analysis which is consistent with dye injection contact area data. Their results for contact stress in terms of initial joint congruity, cartilage thickness distribution, and overall hip compliance provide a convenient basis from which the internal stress pattern alterations can be explored.

METHOD

The finite element technique has emerged as an important tool in the study of mechanical stresses in articular joints, due to the highly irregular geometries, material property distributions, and boundary conditions encountered in such structures. The need for improvements in total hip arthro-