THE EFFECT OF ARTICULAR SURFACE TOPOGRAPHIC VARIABILITY ON ANKLE STABILIZATION

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BACKGROUND:

The articular surface geometry of the superior talar dome involves two adjacent condyles aligned medially-laterally, between which a shallow groove runs from anterior to posterior. The apposing superior tibial-plafond surface has corresponding features, resulting in the high congruency between these surfaces. These anatomical features are thought to contribute to passive stability of the ankle, allowing the small articular surfaces to bear high-magnitude loads during locomotion (up to x5 body-weight [1]). However, the effect of ankle geometry on joint stabilization has not yet been well studied.

Previous experimental studies demonstrated that passive ankle stability under weight-bearing conditions is substantially dependent on articular surface restraint [2,3]. In a recent study, which found that this stabilization mechanism involves reproducible and specific changes of contact stress, we developed a computer model for estimating the magnitude of articular surface resistance associated with these stress changes [4]. As this model was developed as representative of generic ankle geometry, it did not consider the effect of individual anatomical variables, such as the radius and width of talar trochlea, or the depth of the groove.

In the present study, the effect of geometric parameters in this model surface on articular surface resistance calculation was explored. It was hypothesized that differences of ankle geometry impact the capability of articular restraint.

METHODS:

Data from a related cadaver experiment (n = 6)[4], averaged across specimens, were utilized as changes of ankle contact stress associated with secondary loading in this study. In the MTS loading experiment, each specimen, held under a primary axial load (600N) at the neutral position, was subjected to secondary loading. The secondary loading modalities include anterior/posterior (A/P) forces (40 and 80 N, for each), as well as inversion/eversion (IV/EV) and internal/external rotation (IR/ER) torques (150 and 300 Ncm). The associated contact stress changes between the superior-inferior tibial-talar surfaces were monitored by a real-time contact stress transducer (TekScan® #5033, Tekscan Inc., Boston, MA).

These “averaged” contact-stress change data were applied to a computer model analysis implemented in MATLAB® (Version 7.0, MathWorks, Inc., Natick, MA). A model consisting of two adjacent spherical sectors, with 25 mm of spherical radii and 20 mm of separation between centers (the same model as in the previous study), was employed as the baseline model of the articular interface between the superior talar-dome and corresponding tibial-plafond surfaces (Fig. 1). Similar models with scale down (x 0.8 for all dimensions) and with a shallower groove (x 0.5 depth) were also developed, to represent possible individual topographic variables. In these models, contact stresses were assumed to act normal to the model surface. The incremental forces acting on the model surface were resolved into axial, A/P, and medial/lateral (M/L) components. Articular surface resistance associated with the corresponding secondary load was then calculated with use of appropriate force components. Friction was assumed negligible.

With use of these models, magnitude of articular surface resistance associated with secondary loading was calculated from the contact stress change data (Fig. 2). For each secondary loading modality, a set of resistance data were linearly regressed for the correlation to secondary load; the slope of trend line indicates the relative contribution of articular surface resistance to ankle stability. This analysis was applied for all secondary loads, with every model.

RESULTS:

The relative contribution of articular surface resistance to A/P ankle stability was calculated to be greater with the scale-down model, though the impact of groove depth was slight (Fig. 3). The contribution to IV/EV stability was smaller with both scale-down and shallow-groove models. The contribution to IR/ER stability was smaller with the shallow-groove model, though the impact of model scale was minimal.

DISCUSSION/CONCLUSION:

The increase of A/P resistance with the scale-down model can be associated with increase of inclination in the sagittal plane, on the anterior and posterior surfaces where contact stress changes with A/P loading mainly occurred. By similar reasoning, the reduction of IV/EV resistance with both scale-down and shallower groove models was probably due to decrease of M/L force component. The reduction of IR/ER resistance can be associated with decrease of coronal-plane slope on the groove surface, where the trochlea groove and the corresponding ridge of superior tibial surface appear to play a role in resisting IR/ER torques.

The alterations of ankle model surface geometry resulted in credible changes of articular surface resistance to secondary loads, suggesting that differences of articular surface geometry can impact the capability to restrain the ankle. The formulation assumes that the geometrical perturbations are small enough to not appreciably alter the global contact stress distributions; specimen-specific contact solutions would be helpful for assessing detailed effects of anatomical variability or of pathologic abnormality.

REFERENCES:


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