REPAIR OF CARTILAGE DEFECTS WITH AUTOGENOUS OSTEOCHONDRAL TRANSPLANTS (MOSAIC PLASTY) IN A SHEEP MODEL

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Introduction

Joint trauma and disease related degeneration of articular cartilage such as osteoarthrosis pose a problem to human health because of the limited capacity of cartilage for regeneration and the disabling consequences of these conditions. A novel approach to resurface articular cartilage called mosaic plasty which is based on autogenous osteochondral transplantation of grafts is currently promoted as a surgical treatment by Smith & Nephew and others. Historical evidence with osteochondral transplantation suggests that at the cartilage level grafts fail to integrate with the surrounding normal tissue. This study is designed to evaluate the benefit of this procedure in a sheep stifle model. Specifically, this project is to investigate integration of the transplant and filling of the defect at the cartilage level to predict long term outcome. A finite element model of the defect and transplant is used to interpret observed histological results.

Methods

After creating $5x5 \text{ mm}^2$ cartilage defects bilaterally in the trochlear cartilage of adult sheep stifles, the following treatment groups were investigated: I. a square defect left untreated; II. subchondral drilling; III. perfect fit cylindrical autograft in a 5 mm round full thickness defect; and IV. "Mosaic plasty" with a 5 mm diameter graft in a square cartilage defect. Each treatment group included 6 specimens. The stifles were harvested 2 months post-operatively. The defects were macroscopically and specimens were immediately processed for histologic evaluation of the defects and the transplants.

The finite element method was used to simulate cartilage defect and repair experiments. Stress was computed from compressive loads applied to defects in the cartilage only and for full thickness defects filled with osteochondral transplants. The finite element system ABAQUS was used to simulate the experimental configurations. Four models were constructed to simulate effects of loading on the above experimental groups as well as an additional configuration to predict the effect of mosaic plasty in the more general case of multiple transplants in a larger defect. It was assumed that the cortical bone and calcified cartilage of the transplant bonded to the surrounding material. The boundary between the articular cartilage of the transplant and adjacent cartilage was a frictionless contact surface.

All models were based on a three layered system of articular cartilage, calcified cartilage, and cortical bone. The articular cartilage was treated as linear, poroelastic media 0.8 mm thick, while the calcified cartilage and cortical bone were impermeable elastic materials with a combined thickness of 5.2 mm. Nodes at the base of the model and lateral boundaries corresponding to trochlear groove boundaries were pinned. Symmetric boundary conditions were used. Flow was unrestricted through the top of the articular cartilage and across defect boundaries. Loads were applied normal to the surface of the articular cartilage to simulate the patella with a spatial load distribution. Constitutive parameters for the models were calibrated to reproduce experimental data by [1].

Results

Histological results showed degeneration of the cartilage surrounding the defects in groups I and IV, and to a lesser extent in group II. While no obvious signs of degeneration were detected in group III (perfect fit graft), severe degenerative changes of both cartilage and graft were seen in group IV (mosaic plasty). Model results shown in Figure 1 illustrate the early (1 sec) response of cartilage to a Heavyside load function of 0.1 MPa (Figure 1). Results are expressed in terms of the von Mises stresses invariant, a measure of deviatoric stress. Resulting peak von Mises stresses are 0.076 MPa for a perfectly fitting transplant, are 0.25 MPa for an unfilled square defect, and are 0.24 MPa for a cylindrical transplant in a square hole. These stress are the highest at the onset of loading and attenuate somewhat at steady-state when the material loses hydration. The only repair configuration, which entirely suppresses deviatoric stresses, is when the osteochondral transplant fits perfectly into the defect. In this case, free-surfaces of the defect have spatially continuous support from the dowel. This configuration is similar to loading pristine cartilage. In all other cases, significant deviatoric stresses occur along the articular cartilage defect free-surfaces and where these surfaces contact calcified cartilage. As expected, significant von Mises stresses occur along the boundaries of the entire defect in the unrepaired defect. The lateral continuity of the defect allows strain to increase toward the unsupported symmetry boundary and the vertical corners of the defect provide minimal support. Results suggest a poor fitting osteochondral transplant increases the von Mises stresses. The transplant provides partial support to the defect free surfaces, however, significant von Mises stresses still exist in the unsupported regions.



Figure 1. von Mises stress distributions for cartilage defects filled with a cylindrical osteochondral transplant. The corner of the figure represents the center of the osteochondral transplant and the exposed sides are planes of symmetry. On the left is a perfectly fitting tranplant in a circular defect. On the right is a cylindrical transplant in a square defect. Note the much higher stresses near the unconfined cartilage surfaces corresponding to observed cartilage degradation in the animal model.

Discussion

Results predicted by the models are in agreement with observed articular cartilage degeneration associated with defects and osteochondral transplants in the experimental animals. This poroelastic model provides a biomechanical explanation for the observed experimental results and points out the need for either perfectly fitting transplants or a filler material to provide continuity of the surfaces. Both experimental results and model results point out severe limitations of the mosaic plasty procedure and predicts poor result.

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References

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