Shear Loads on Cartilage Tissue Supporting Scaffolds Can Be Measured Using Embedded Strain Gauges

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Introduction

In a healthy joint, articular cartilage is subjected to a dynamic loading environment consisting of both shear and compressive forces. While physiologic compressive loads have been shown to stimulate matrix repair and maintenance, excessive shear stresses can result in cartilage destruction and ossification. Although cartilage typically experiences direct compressive loading due to the low coefficient of friction of the articulating surfaces, any disruption to the native joint mechanics can increase shear loads in the joint. Following reparative surgery, the native mechanical environment can be altered such that shear stresses are increased by as much as 450%. *In vivo* measurements of shear forces could be used to better understand activities and protect newly repaired cartilage tissues. The ability to detect *in vivo* loads will also help establish rehabilitation exercises that facilitate cartilage repair and limit cartilage shear loading.

Novel strain-gauged scaffolds have been used in tissue engineering projects to measure axial loading in the canine stifle joint. Strain gauges placed near the articulating surface of a scaffold used to support tissue-engineered cartilage could provide *in vivo* diagnostics of the shear-loading environment. The goal of this study was to develop a technique to place strain gauges under the dome of PBT scaffolds to provide relevant real time shear-loading measurements and evaluate the performance of this system.

Methods

Polybutylene terephthalate cylindrical scaffolds (9 mm diameter) were manufactured using free form fabrication with a domed surface following the model used in a current tissue engineering study. This design incorporates a solid layer of PBT between the dome and the cylinder base to create a vascular barrier between the subchondral bone and the engineered tissue. This dome surface of each scaffold was mechanically removed just below the solid layer and rosette strain gauges were attached to the underside of the dome. Strain-gauged domes were then reattached to the cylindrical bases with epoxy. An aluminum mount was created to interface with a MTS. A bolt was machined to a flat edge and attached to the MTS load cell and an aluminum mount was attached to the ram. Scaffolds were placed in the mount leaving the domes exposed, while the rosettes were wired to strain gauge signal conditioners. Scaffold domes were loaded in shear to peak loads of 50N at 50N/s to simulate shear loading of the scaffolds. Each scaffold was reloaded ten times and measurements were averaged and standard deviations were calculated.

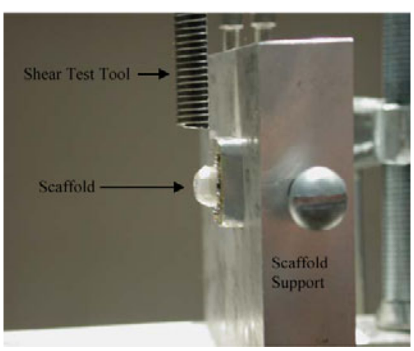

Figure 1. Side view of scaffold being shear loaded.

Results

Strains measured from attached sensors were proportional to applied shear loads. The greatest sensitivity was found to vary between gauge orientations. Average strains measured per applied load from within the scaffolds varied from scaffold to scaffold. On average, they ranged from 0.57 μstrain/N ± 14% to 0.82 μstrain/N ± 45%. As expected strain patterns within each scaffold varied reflecting the variation in sensitivity of gauges based on their alignment with respect to the direction of the applied load. Measurement indicated that the PBT domes on the scaffold experience significant deformation along the direction of loading as well as substantial deformation along the periphery of the dome.

Discussion

Measurements collected during this study show the potential for measuring the principal strains and shear strains on the surface of the scaffold. If we assume that the free surface on which the strain rosette is attached is in a state of plane stress, the normal direction of the free surface is a principal axis for strain and the principal stresses can be calculated. Given that the thickness of cartilage is small, compared to its plain dimensions, it is reasonable to assume plain stress and strain. These measurements provide valuable insight into the mechanical environment of joints. These results also hold promise that strain gauges can also be placed inside scaffolds in a three-dimensional configuration in order to determine the complete mechanical loading mechanics of the joint.

The sensitivity variation noted in the measurements may have been a result of gauge location variation. Gauge proximity to the exterior of the dome may also influence accuracy of bulk measurements. A sensitivity analysis examining these parameters is underway.

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