A Novel Fiber-Reinforced Scaffold for Reconstruction of the Meniscus

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INTRODUCTION:
The meniscus is a C-shaped disc of fibrocartilage that plays a critical role in the protection of the articular cartilage of the knee by transmitting loads through the joint, distributing high stresses evenly on the underlying surfaces, providing shock absorption, and aiding in joint lubrication. Despite the recognized importance of the tissue, arthroscopic removal of a torn meniscus is one of the most commonly performed orthopaedic operations in the United States. Long term follow-up of total and subtotal meniscectomies has consistently shown the positive correlation between degenerative changes in the knee and the amount of meniscal tissue removed. Unfortunately, due to the limited vascularity of the meniscus, and consequently, its limited healing potential, few viable alternatives exist for significant meniscal deficiency. Current scaffolding and allograft technologies have not demonstrated the long-term clinical success necessary to be considered the ‘gold standard’ for meniscal replacement. We are currently developing a fiber reinforced meniscus analog whose design is based on the geometry and microstructure of the normal meniscus. The objective of this preliminary study was to explore the potential utility of the scaffold as a replacement for deficient meniscal tissue. This was accomplished by evaluating the biocompatibility of the device implanted in the harsh synovial environment of the knee joint.

METHODS:
Scaffolds were fabricated by weaving a resorbable polymer fiber, poly(DTD DD), into an organized pattern, mimicking the geometry of the meniscus and forming two strong anchor points for attachment to the tibial plateau. A mold was formed around the weave and then a collagen dispersion with Hyaluronic Acid (HA) and/or Chondroitin Sulfate (CS) was injected into the mold. This was frozen, lyophilized, and cross-linked with EDC resulting in a collagen sponge embedded with fibers arranged to provide circumferential and radial strength to the construct.

The biological incorporation of fiber-reinforced scaffolds was evaluated in a non-functional in vivo evaluation. Sections of scaffolds were inserted into surgically created synovial pockets of 10 New Zealand White rabbits (one per knee for a total of 20 implants). Scaffolds were positioned such that they were exposed to the harsh enzymatic environment of the knee, while carrying no mechanical load, or interfering with joint function. Animals were sacrificed at either 4 (n=5) or 8 (n=5) weeks. The scaffold sections were excised, fixed in formalin and then processed for standard histological analysis. Slides were analyzed and graded in a random, blinded fashion by a pathologist for inflammation, vascularization, neo-tissue formation, and scaffold degradation. All surgeries were performed using an IACUC approved protocol.

All results were statistically analyzed using a two-way ANOVA with pair wise comparisons by the Student-Newman-Keuls method.

RESULTS:
Gross observations of the excised scaffolds showed no negative host response to the implants. The implants were firm and showed signs of good tissue in-growth. Histological sections showed that all implants had cellular infiltration throughout the scaffold. However, scaffolds without GAGs were generally less cellular. Lymphocyte inflammation was associated primarily with the collagen sponge portion of the scaffold, and the presence of multi-nucleated giant cells was associated primarily with the fiber portion of the scaffold. There was a decrease in lymphocyte inflammation from 4 to 8 weeks. There was also an increase in vascularization from 4 to 8 weeks. Partial degradation of the collagen matrix was observed at the four week time point and nearly all original matrix was gone by the eight week time point. As expected, polymer fibers remained intact throughout both time points. Implants containing GAGs trended towards more organized deposition of new collagen making a more ‘meniscus like’ structure. No differences were noted between scaffolds with HA alone or both HA and CS.

DISCUSSION:
The purpose of this study was to determine if a fiber-reinforced collagen sponge which mimics the geometry and microstructure of the meniscus would be a viable candidate for meniscal replacement from a biological incorporation perspective.

Results from the in vivo study suggest that the scaffold with HA or HA and CS elicits a biological response conducive to its incorporation, degradation, and eventual replacement with native tissue. While the collagen portion of the scaffold is almost completely replaced by cells and amorphous tissue at 8 weeks, the presence of the polymer fibers shows that despite the harsh synovial environment of the joint, the primary load-bearing portion of the scaffold will persist. This is important for a meniscus scaffold, which needs to provide mechanical function for a relatively extended period of time as new collagen is deposited and organized into a structurally sound tissue. It is yet unclear what long term role CS or HA will have on the biological incorporation of the scaffold in a functional model. Based on these results, this fiber reinforced meniscus scaffold is a promising alternative for meniscal replacement.

SIGNIFICANCE:
With 1.5 million meniscus tears occurring per year, and a considerable backlog of untreated injuries, the worldwide market for a meniscus replacement device has been estimated at $1.5 billion annually. Unfortunately, few treatment options exist for significant meniscal deficiency, and there is currently no FDA approved device for replacement of the meniscus.

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