INTRODUCTION:
Intervertebral disc function is dependent on the ability of the inner nucleus pulposus (NP) to effectively pressurize against the outer annulus fibrosus (AF). If the annulus is damaged or weakened, the disc bulges, impinging on surrounding nerves causing pain and discomfort. Repair of focal defects in the annulus resulting from trauma or medical intervention is challenging. Mechanical devices such as sutures, anchors and barricades either fail mechanically or due to lack of healing at the defect site[1,2]. To date there are no materials or devices that can be easily delivered to AF defects that would both restore mechanical function and promote healing through integration. Previously we have reported that collagen gels used in tissue engineered total disc replacements integrate well with adjacent native AF tissue [3,4]. The goal of this study is to determine the ability of high density collagen gels to repair damages and contribute positively to mechanical function in an intervertebral disc (IVD) defect model.

METHODS:
Rat caudal motion segments (bone-disc-bone) were excised from thawed Sprague-Dawley rat tails and cleaned of all tissue and ligaments. Defects were created in discs at two sizes: 1) using a 21-gauge (21ga) beveled needle to break the AF and a 0.70mm diameter precision tip to give the defect uniformity and 2) using a #11 scalpel blade to remove a patch of AF for a larger defect (Figure 1). Stock collagen gels (12 and 20 mg/ml) were mixed with working solutions to create final collagen patch of AF for a larger defect size and collagen concentration. Gels remained in place at intradiscal pressures up to 83.6 kPa. Although there was a slight effect on disc modulus, there was a greater effect on the hydraulic permeability. This shows that the gel is impeding the flow of water out of the disc and enabling re-pressurization after gel treatment. This pressurization is crucial to proper disc function.

It is important to note that the gels were more effective at repairing smaller defects, which can be helpful in minimizing damage from diagnostic procedures (i.e. discography). There were differences between 10 and 15 mg/ml densities; however an optimal concentration has yet to be identified. Additional densities will be added to the next phase of testing in order to identify a range best fit for annular repair. This study shows the direct mechanical effect of the gel alone, with very encouraging results. However the gels can be modified to deliver cells and growth factors to encourage tissue growth. More can also be done to enhance the gel mechanical properties, such as crosslinking. As such we show that high density collagen gels are an appropriate platform for repair of annular defects.

RESULTS:
Upon gross inspection of the frozen bisected samples, there were traces of dyed gel both within and on the outside of the disc as well as an unorganized region within the AF (Figure 1). The small 21-gauge and larger scalpel blade defects both decreased modulus and increased hydraulic permeability in the native rat IVDs. The larger defects were more severe, with up to a 70% drop in modulus values and a 4-fold increase in permeability (Figure 2).

Filling the defects with either 10 or 15 mg/ml gels had a small effect on instantaneous modulus values, with the data showing a 5-10% increase from damaged to filled. This increasing trend was also exhibited in equilibrium modulus values. There was a significant effect on hydraulic permeability with a 50% decrease in permeability from the damaged values with 15 mg/ml gels in the 21-gauge defects. The 10 mg/ml gels also decreased permeability by 32% of damaged values in 21 gauge defects. Although there are visible trends in the scalpel blade data, they are less pronounced and could be attributed to sample variability.

DISCUSSION:
Injectable high density collagen gels enhance the mechanical function of damaged IVDs. Gels remained in place at intradiscal pressures up to 83.6 kPa. Although there was a slight effect on disc modulus, there was a greater effect on the hydraulic permeability. This shows that the gel is impeding the flow of water out of the disc and enabling re-pressurization after gel treatment. This pressurization is crucial to proper disc function. It is important to note that the gels were more effective at repairing smaller defects, which can be helpful in minimizing damage from diagnostic procedures (i.e. discography). There were differences between 10 and 15 mg/ml densities; however an optimal concentration has yet to be identified. Additional densities will be added to the next phase of testing in order to identify a range best fit for annular repair. This study shows the direct mechanical effect of the gel alone, with very encouraging results. However the gels can be modified to deliver cells and growth factors to encourage tissue growth. More can also be done to enhance the gel mechanical properties, such as crosslinking. As such we show that high density collagen gels are an appropriate platform for repair of annular defects.

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