EVALUATION OF ACL REPAIR WITH MAGNESIUM-BASED RING USING AN IN VITRO ROBOTIC TESTING SYSTEM

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INTRODUCTION

The anterior cruciate ligament (ACL) is injured over 100,000 times per year in the U.S. alone[1]. These injuries occur commonly in sports with cutting or pivoting motion, such as football, basketball, and ultimate Frisbee, and can have healthcare costs of $1.5 billion per year[2]. The ACL, located in the knee between the tibia and femur, prevents the tibia from moving in the anterior direction with respect to the femur. It also limits rotational movements of the knee to provide stability. Upon injury, the ACL is usually treated because ACL deficiency has been shown to lead to pain and osteoarthritis[3]. Additionally, ACL deficiency has been shown to damage other soft tissues in the knee and contribute to poor knee stability[3]. ACL reconstruction is currently the most common form of treatment. With ACL reconstruction, the surgeon takes a graft, commonly from the hamstring, and uses this to replace the ACL in the knee. This has been shown to lead to donor site morbidity. In addition, long term studies have shown that reconstruction can also lead to premature osteoarthritis[4]. Therefore, scientists are looking for a new treatment option for patients. In the past, there was limited potential for healing a torn ACL. Recent advances in tissue engineering have shown that ACL healing could be a viable option[5].

Previous research in ACL healing has used a combination of sutures and a porcine small intestine submucosa extracellular matrix (ECM) to repair the ACL[6]. An ECM sheet was applied around the injured ligament. Further, ECM in hydrogel form is injected into the wound site to accelerate healing. The sutures are used to align the ACL initially, while the ECM is used to stimulate the healing over time. While this study was successful in repairing the ACL, there was still a need for initial joint stability. The ACL was not properly loaded, and therefore allowed for disuse atrophy of the ACL insertion sites[7].

Based on previous research, a new method is needed to initially mechanically augment the ACL. A magnesium-based ring, previously optimized for surgical implantation, could restore this initial joint stability and load the ACL at the insertion sites. It is hypothesized that using a biodegradable magnesium-based ring to bridge the gap between the two transected ends of the ACL will reduce the translation of the knee and increase the forces carried by the ACL. For this experiment to be successful, the knee translation with the repaired ACL should be within 5 mm of normal knee translation. Additionally, the forces carried by the ACL should be within 10 N of the intact ACL.

METHODS

This experiment tested n=8 goat knee joints using a robotic/universal force-moment sensor (UFS) testing system. This robotic testing system has six degrees of freedom. To prepare the specimens for testing, excess soft tissue is removed from the knee joint. The tibia and femur are potted in a mold to fit tightly into the robot’s clamp. The femoral clamp is attached to a pedestal base, so the femur remains stationary during testing. The tibial clamp is the effector end of the robot, simulating a clinical exam. This robotic testing system is used to employ force control and position control. In force control, the robot applies forces to the tibia and measures the resulting translation of the tibia. The loading conditions used in the experiment were a 67 N Anterior Tibial Load (ATL) and a 67 N ATL + 100 N Axial Compression. In position control, the robot applies kinematic position data to the knee, and measures the resulting forces in the knee. Tests were completed at 30, 60, and 90 degrees of flexion.

The first step of testing is to run the passive path. This procedure moves the joint from full extension to 90 degrees of joint flexion and finds the position where the joint forces and moments are minimized. These positions serve as a reference position to move the knee joint between different flexion angles later in testing. The next step was to test the knee while the ACL was still intact. Force control was run to gather knee translations. Next, the ACL was transected. The ACL deficient knee was tested with position control, using the kinematics from the previous trial. Using the principle of superposition, this found the force carried by the ACL. Next force control was applied to the ACL deficient knee to find the translations. Next the ring was implanted into the knee. The ring-repaired knee was tested with force control to find the translations of the knee in the ring-repaired state. The ring was removed and position control was applied to find the force carried by the ACL in the ring-repaired state.

After data collection from the robot, a repeated measures ANOVA and Bonferroni correction was used to compare between the intact and ring-repaired knee, with statistical significance indicated if p<.05. This statistical analysis was used because three different measurements taken from a single joint are compared.

RESULTS

The values calculated for comparison were stated as the mean across all joints tested under each condition. Results are displayed only for the 67 N ATL condition, as consistent results were found with the 67 N ATL + 100 N Axial Compression loading condition. Figure 1 shows knee translation in all three states at each flexion angle.
As seen in this figure, knee translation increased by more than 10 mm after the ACL is cut. After ring implantation, the translation decreases by more than 5 mm. The translation of the ring-repaired knee is within 5 mm of intact. Figure 2 displays the force carried by the ACL in the intact and ring-repaired state.

As seen in the figure, the forces carried by the ring-repaired ACL are within 10 N of the intact ACL.

The statistical analysis results showed statistical significance (p<.05) between the intact ACL and the ACL deficient knee translations, as well as between the intact ACL and the ring-repaired knee translations. Comparison between the forces of the intact ACL and ring-repaired ACL also gave a p>.05, so these cannot be considered statistically different.

**DISCUSSION**

The results of this experiment supported our hypothesis that using the magnesium-based ring would restore initial joint stability by reducing the translation of the knee and loading the ACL. Though they were statistically different, it was proven that knee translation using the ring could be confined to within 5 mm of the intact ACL, meeting the initial objective. Additionally, the ACL was properly loaded within 10 N of the intact when using the ring repair. The reduction of the knee translation will contribute to the initial joint stability after repair, while the loading of the ACL will prevent disuse atrophy. These two issues were minimized through use of the Mg-based ring.

In the future, this ring will be tested *in vivo* to see the longer term results. The ring will be implanted and the ECM will be applied to stimulate the healing. Over time, the ring should degrade and the subject will be left with just the original, healed ACL. Success in the goat *in vivo* studies could eventually lead to human testing. Ultimately, in the future, the Mg-based ring could be used as a new treatment option for patients who suffer from an ACL injury.

**CONCLUSIONS**

ACL injuries occur very frequently in the US. With recent advances in tissue engineering, healing the ACL could be a very viable future treatment option. This experiment showed that using a magnesium-based ring can restore the initial joint stability that other healing studies have not yet shown. Knee translations were reduced and forces carried by the ACL were very close to intact. Using this ring in combination with an ECM could lead to a new treatment option for patients with ACL.

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**REFERENCES**


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