Musculoskeletal Research Center

Summer Research Program

Department of Bioengineering

University of Pittsburgh

MSRC

2012

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Editor's Note

The class of 2012 summer interns were a small, yet diverse and dedicated, group of students. Ching travelled from The Chinese University of Hong Kong to gain experience at the MSRC. In addition to sharing the summer with an international student, we also found it valuable to learn from interns from different institutions and with different educational experiences. Jonquil, a graduate student from North Carolina A&T, was able to act as a mentor along with the graduate students at the MSRC. Jillian, who recently graduated from CMU with degrees in biology and psychology, brought her valuable knowledge regarding cell work. Lastly, Hunter and I were able to add to the MSRC community by sharing the education that we had received as bioengineering students at Pitt as well as the experience that we had already gained as undergraduate researchers at the MSRC.

I speak for all of the summer students when I say that this summer has been an extremely worthwhile and enjoyable experience. We are so very grateful that the faculty and graduate students at the MSRC took the time to share their expertise, skills, and passion for research with us this summer and would like to extend a special thanks to Dr. Woo, Kwang Kim, and Katie Farraro. We will always remember the lessons that we have learned and will apply them to any future endeavor that we may pursue.

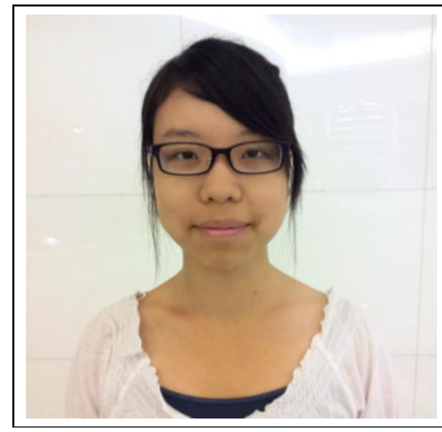
The work presented in this abstract book represents the hard work and efforts of the interns who performed research at the MSRC this summer. We are very proud of the work that we have performed and excited to share it!

- Aimee Pickering, Editor

Summer Symposium Committee

Hunter Eason

Jillian Cheng



Wai-ching Yu

This year's symposium demonstrated the hard work of all of the participants in the MSRC Summer Research Symposium. All participants did a great job of presenting their work from the summer. The following abstracts give a glimpse of the work put into the research by the summer programs participants. This year there was research on ACL reconstruction, ACL healing, and screw design using finite element analysis.

Everyone who took part in the Summer Research Program would like to thank all the faculty, staff, fellows, and graduate students at the MSRC. Without their assistance, we would not have been able to gain the skills and knowledge necessary to conduct our research.

Finally, we would like to thank Dr. Woo. Without his guidance and willingness to share his experience in research, the MSRC Summer Research Program would not be nearly as impactful to its participants as it currently is.

- Hunter Eason, Symposium Committee Chairman

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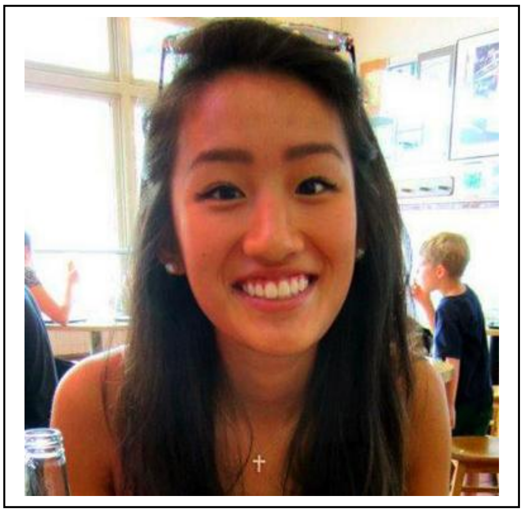

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I was birthed on June 10, 1990. Born and raised on Long Island, New York, I enjoyed reading, roughing it up with my brother and friends, playing the cello, and lacrosse. At the tender age of 13, I was uprooted from my comfortable life in Melville and was taken to the unfamiliar country that is Taiwan. Fortunately, I was able to overcome culture shock and develop a love for the country as well as all the opportunities it provided me.

I made the decision to attend Carnegie Mellon University because not only does it excel in engineering and the sciences, but it is also top-ranked in business, psychology, fine arts, and many more. I wanted to take advantage of opportunity to receive a well-rounded education. Hence, I majored in Biological Sciences and Psychology, with a minor in Business Administration. In college, I participated in various organizations, from being the treasurer of the Taiwanese Students Association to the Vice President of Public Relations of my sorority, Kappa Alpha Theta. I also stayed active by playing club lacrosse and intramural softball.

My interest in biomedical engineering developed as a result of my biomedical research work under a pediatric surgeon, Dr. James Dunn, at UCLA two summers ago. This internship opened my eyes to the possibility of improving the human condition through innovative science. I gained insights as well as hands-on experience with cell culturing, tissue engineering, tissue transplantation, and biomedical device design. To diversify my experience, I did research in Dr. Kimimasa Tobita's lab at The Children's Hospital in Pittsburgh last summer. When I put my findings towards a poster presentation, I was awarded first place in the Summer Symposium. The experiences at UCLA and The Children's Hospital of Pittsburgh were incredibly fulfilling and fueled an interest in biomedical research and application. I find the unique mix of engineering, medicine, and life sciences invigorating. In addition, Carnegie Mellon has given me a drive to create cutting-edge technologies and scientific solutions and has provided me with an organic blend of information and hands-on experience.

This summer, I have had the great opportunity to work at the MSRC. I would say that this summer research experience has been the most rewarding research experience I have had to date. Not only was I given the opportunity to work independently on my research project, but I also learned valuable lessons in presentation, work ethic, and collaboration.

THE EFFECTS OF DIFFERENT MAGNESIUM ALLOYS ON ACL FIBROBLAST CELL VIABILITY AND PROLIFERATION

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INTRODUCTION

Magnesium alloys have attracted a lot of attention as a potential biodegradable material [5]. This is due to many of its features including sufficient strength, good degradation rate, and good biocompatibility. Some of the major biocompatibility advantages that magnesium alloys provide include its essentialness to human metabolism [7], ability to increase cell proliferation in cells [6], safe release into the body, and activeness in cell adhesion mechanisms [3]. Not only is magnesium the fourth most abundant cation in the body [4], the highest corrosion rate in currently reported Mg alloys is still far below the daily allowance of Mg in the body. Thus, these factors make it a strong candidate as a biocompatible material.

Magnesium alloys are currently being used and have been studied as implants in the bone. Research done on Mg alloy implantation in the bone has shown an increased bone mass around the implant, which means there is bone cell activation [9]. Furthermore, Mg alloys coated with Ca-P showed a significant increase in cell number [8]. From the positive effects shown of Mg alloys and its previous applications in bone implantation, there is now an interest in studying how Mg alloys can be beneficial to anterior cruciate ligament (ACL) healing.

The ACL is one of the most commonly disrupted ligaments in the knee. Most patients with ACL injury undergo surgical reconstruction [1]; however, 20-25% of the patients suffer from unsatisfactory results, such as donor site morbidity, osteoarthritis, and residual pain [2]. From these results, it seems that there is a need for a better method of improving ACL healing. Magnesium alloys could come into play by facilitating ACL healing post-reconstruction. It could provide temporary support around the repaired ACL tissue, as well as provide stimulatory effects on ACL fibroblast cell growth when in close proximity to the tissue. Therefore, a deeper understanding of how Mg alloys can affect ACL fibroblast viability and proliferation must be obtained.

OBJECTIVE

The objective of this study is to determine which magnesium alloy composition would provide the most optimal environment for ACL fibroblast viability as well as proliferation. The first part of this study involved culturing a healthy batch of rat fibroblast cells to be seeded into wells containing the metal samples. The MTT Assay and the Live/Dead Cell Proliferation Assay were then used to compare the amount of ACL fibroblast viability and proliferation of each sample.

MATERIALS AND METHODS

Five magnesium alloys in addition to pure magnesium were tested in this study: AZ31, ZK40, WXK110, WXK410, and WXAK, which consist of elements such as silver, yttrium, zinc, zirconium, calcium, aluminum, and silver. Anterior cruciate ligament fibroblasts were isolated and harvested from rats. The tissues were minced and then digested with collagenase for two hours on a shaker at 37°C. The digested tissues were then resuspended in 10 ml of culture medium containing low glucose Dulbecco's modified Eagle medium (Invitrogen, Carlsbad, CA), 10% fetal bovine serum (Invitrogen, Carlsbad, CA), and cultured at 37°C. The cultures were given ample time to expand and were passaged up until Passage 2 (P2). P2 cells were used in the MTT Assay with Mg alloys and the Live/Dead Cell Proliferation Assay.

Metal samples were prepared according to the protocols for each assay. For the Live/Dead assay, both sides of the samples were UV sterilized for 30 minutes each in 12-well plates. They were incubated in αMEM + 10% FBS + 1% P/S for 10 minutes and then the media was removed. The ACL fibroblasts were seeded onto each sample directly at 100,000 cells/ml for 2 ml, with two negative controls. This was then cultured for three days before the assay was performed. After three days, the samples were carefully transferred to new well plates containing 1 ml of PBS. The PBS was removed, and ethidium bromide and calcein were both added. After 30 minutes in the dark, the metal samples were observed under fluorescence microscope and pictures were taken.

For the MTT Assay, the metal samples were UV sterilized on both sides for 30 minutes each before being incubated in phenol red-free αMEM + 10% FBS + 1% P/S for three days. The metal sample extracts are filtered into vials and diluted accordingly (e.g. 100%, 50%, 25%, 10%). The cells are seeded onto 96 well plates at 100,000 cells per well and cultured for one day in phenol red-free αMEM + 10% FBS + 1% P/S. After the media is removed, 100 µl of Mg alloy extract is added to each well, with each extract dilution having three replicates for each sample. The samples were cultured for three days before performing the assay. After three days, MTT is diluted and dissolved in 5 mg/ml of PBS, enough for 10 µl per well. Phenol red-free media was added to MTT at 10x media to MTT, enough for 100 µl per well. The media in the plates were removed, and 110 µl of the media and MTT solution was added and incubated at 37°C for four hours. After incubation, 100 µl of an SDS and HCl solution (1g SDS in 10 ml of 0.01 M HCl) was added to each well using a micropipette, mixed thoroughly. The samples were incubated for another 4 – 18 hours. After incubation, the solution in each well should have turned yellow, in which case, the absorbance was read at 570 nm using a plate reader.

The data was obtained from both assays and used for comparison among the metal samples for ACL fibroblast cell proliferation and viability.

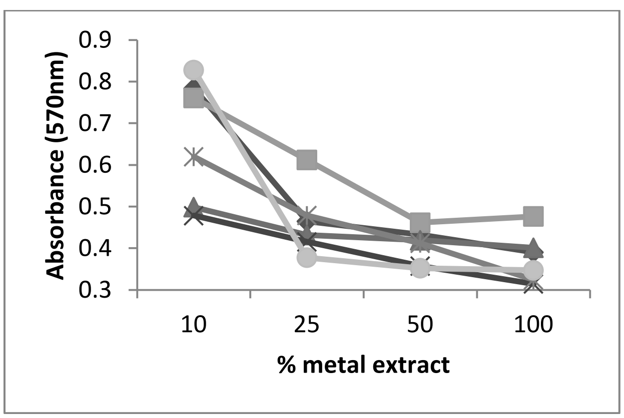
Table 1. Summary of ACL fibroblast cell proliferation on varying Mg alloys; data from on trials of MTT assay

% dilution	Mg	AZ31	WXAK	WXK110	WXK410	ZK40
10	0.784	0.761	0.499	0.478	0.620	0.828
25	0.465	0.612	0.432	0.415	0.479	0.378
50	0.433	0.461	0.419	0.357	0.412	0.352
100	0.390	0.476	0.401	0.314	0.324	0.347

RESULTS

From the Live/Dead cell viability and proliferation assay, the control showed cell viability, but the cell viability on the alloy samples were unable to be distinguished. In addition, there were not enough metal samples in stock for use to complete more than one trial. Therefore, the data from the one Live/Dead assay was deemed inconclusive.

Of the three MTT Assay trials that were run, only one was successful in producing a purple color that was measurable. The absorbance readings were obtained and can be seen in **Table 1**. From this preliminary data, there seems to be a general trend in which cell growth decreases as percent metal extract dilution increases. In addition, AZ31 (Mg-Al-Zn) may be superior in providing an optimal environment for cell growth as compared with the other Mg alloy samples. The positive control showed an absorbance of 0.340. With increases of percent metal extract dilution for some samples, there is a negative effect on cell proliferation, as shown by absorbance readings that are lower than 0.340 in sample WXK110 (Mg-Y-Ca-Zr), WXK410 (Mg-Y-Ca-Zr), and ZK40 (Mg-Zn-Zr). **Figure 1** displays the cell growth as measured by absorbance at 570nm and percent metal extract.



DISCUSSION

The purpose of the study was to determine which magnesium alloy composition, of the six available, would provide the most optimal environment for ACL fibroblast growth and health, in hopes of being useful as a scaffold in ACL regeneration. Two assays were performed in order to measure cell proliferation and cell viability – the MTT Assay and the Live/Dead Cell Viability Assay.

Healthy P2 ACL fibroblast cells from rats were cultured and used in the assays. Of the one Live/Dead Cell Viability Assay trial performed, data was inconclusive due to an inability to distinguish cell viability on alloy samples. It may be possible that the samples degraded with uneven surfaces and thus made it more difficult to view under the fluorescence microscope. In addition, poor technique as well as unsuccessful cell attachment to metal samples could also have been factors. Of the data obtained from the MTT Assay, it seems that AZ31 may be more superior to the other metal samples in providing a good environment for cell growth. There was also higher cell growth shown in pure magnesium extract than in some of the alloys. This may be because of the alloying of yttrium to some samples. Yttrium may have had toxic effects on cells, resulting in lower proliferation. However, the data is preliminary and more testing must be done to confirm these results. Because the data was only collected from one assay, statistical significance of the data could be not achieved, nor can the results be conclusive.

Future work will include both short-term and long-term objectives. Short-term objectives will focus on perfecting the technique for testing cell proliferation using the MTT Assay, and perform more MTT Assays to collect more data for better reliability in results. In addition, problems faced with the Live/Dead Cell Viability Assay will be addressed and improved upon. Being able to successfully perform both assays will increase the reliability for cell proliferation results as well as provide the ability to understand how viable and healthy the cells are. Long-term goals include starting with each Mg alloy component separately and testing their individual effects on ACL fibroblast cell proliferation as well as incorporating growth factors onto the metal samples to provide a better environment for cell proliferation.

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I was born November 9, 1990 in Orlando, Florida. My family has moved numerous times since I was born and I have lived in Florida, South Carolina, Virginia, Illinois, Pennsylvania, and Texas. My father is a nuclear engineer and my mother is a homemaker. I have two older brothers and two younger sisters, the youngest of which my family adopted from China. I graduated high school while living in Lancaster, Pennsylvania where I played football and ran track while also participating in National Honor Society, the school newspaper, and our schools Junior Engineering Team (JETs). Outside of school, I was an active member of the Boy Scouts of America and became an Eagle Scout when I was 17. The combination of serving others through Boy Scouts combined with my work with JETs led me to choose Bioengineering as a major, and has driven my goal of attending medical school post graduation.

I am going to be a senior this fall at the University of Pittsburgh. During my three years at Pitt, I have been a preceptor for FHEP, which aids freshmen honors engineering students in their transition from high school to college, worked as undergraduate lab teaching assistant for general chemistry labs, joined Tau Beta Pi, the national engineering honors society, and studied abroad in Ireland. When not performing school work, I enjoy playing pick-up sports such as football, basketball, and ultimate Frisbee with my friends, reading, watching movies, and exploring the large variety of activities Pittsburgh has to offer like the Carnegie Museum and Phipps.

I began working at the MSRC during the spring of 2011 and besides my semester abroad I have worked at the MSRC since then. The experience I have gained while performing research at the MSRC has been one of the most valuable forms of education I have received while attending college. The best part of working at the MSRC is the people I get to work with. I have worked under an outstanding graduate student, Katie Farraro, who has been an outstanding mentor. I thank her and could not have asked for a better graduate student to work with. I have had the privilege to work with two different surgical fellows, one each summer, at the MSRC. I thank Dr. Andrea Spezialli for his work on the Mg-based ring project this summer. Finally, I would like to thank Dr. Woo for welcoming myself and all the other summer interns into his lab while providing us with guidance on our research projects.

DESIGN AND EVALUATION OF A MAGNESIUM-BASED RING FOR REPAIR OF A TORN ANTERIOR CRUCIATE LIGAMENT

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INTRODUCTION

The anterior cruciate ligament (ACL) is frequently injured during sports and work-related activities, with over 100,000 cases in the United States each year [1]. ACL injuries can lead to joint instability, damage to other structures in the knee, and osteoarthritis [2]. Due to the ACL's low healing capacity, the current gold standard treatment for ACL injury is reconstruction [3]. However, while this treatment has been shown to provide satisfactory short-term results in terms of restoring joint stability, follow-up studies of 10 years or more post-surgery show a significant number of reconstructions result in unsatisfactory long-term results, such as osteoarthritis and donor site morbidity [4,5].

These complications and recent advances in tissue engineering have led to the exploration of ACL healing as a potential alternative to reconstruction. ACL healing could avoid the complications associated with ACL reconstruction and preserve the complex anatomy of the ACL, including its proprioceptive nerve fibers, double-bundle structure, and broad insertion sites [6,7]. To this end, a previous study conducted at our research center demonstrated that using an extracellular matrix bioscaffold for biological augmentation of a transected ACL could accelerate tissue formation and improve the structural properties of the femur-ACL-tibia complex (FATC) at 12 weeks of healing in a goat model. However, anterior-posterior joint stability remained inferior to the normal ACL and tissue healing was slow [8]. In addition, a subsequent 26 week healing study performed at our research center showed that the failure mode of the FATC during uniaxial tensile testing switched from the midsubstance to the insertion sites. This led us to believe that a lack of loading of the healing ACL could have led to disuse atrophy and degradation at its insertion sites.

We believe that additional mechanical augmentation of the healing ACL is needed in order to restore anterior-posterior joint stability and load the healing ACL at time zero. Specifically, the addition of a ring structure to connect the two ends of the injured ACL could provide extra mechanical support during the early stages of healing. The ring structure is composed of magnesium (Mg) alloys, which could be designed to degrade at a rate consistent with ACL healing.

OBJECTIVE

The objective of this study was to design a magnesium (Mg)-based ring that could load the ACL and reduce anterior tibial translation (ATT), as well as create a feasible implantation technique to surgically attach the ring to a surgically transected ACL.

MATERIALS AND METHODS

The ring design was based on the geometric dimensions of the goat ACL. The ring is circular in cross-section with a thickness of 0.5 mm, with a larger diameter on the tibial side to correspond to the ACL's fan shape. Three ring sizes were constructed: the first with diameters of 5 and 6 mm, the second 6 and 7 mm, and the third 7 and 8 mm. Each ring is 6 mm long with four notches along each end to fix it in place with sutures (**Figure 1**).

The implantation technique was developed with assistance from orthopaedic surgeons. First, the ACL is exposed and transected. Then, two sets of sutures are passed through each stump twice. These sutures are then threaded through the ring, pulling it into place, and tied under tension in notches. Once the ring is attached to the ACL, four bone tunnels are drilled; two anterior to the femoral insertion site and 1 medial and 1 lateral to the tibial insertion site. A second set of sutures is passed through the ACL stumps and secured in the remaining notches of the ring before being pulled through the bone tunnels opposite them and fixed under tension (**Figure 2**).

To confirm that the ring design and implantation technique would reduce ATT and load the ACL, preliminary robotic testing with goat stifle joints was conducted using our laboratory's robotic/UFS system (N=2). The robotic system can accurately reproduce 6 degrees of freedom motion, while the UFS measures three forces and three moments. With these capabilities, this system allows both joint kinematic and in situ force data to be obtained by acting in either force or position control modes. Acting in force control mode, a 67 N anterior tibial load was applied to the joint to determine ATT of the joint when it was intact, deficient, and repaired with the Mg-based ring at three angles of knee flexion (30, 60, and 90 degrees). Switching to position control mode and repeating the kinematics of the joint in response to the 67 N anterior tibial load allowed the in situ forces in the intact ACL and repaired ACL to be obtained at the three angles of knee flexion by using the principle of superposition.

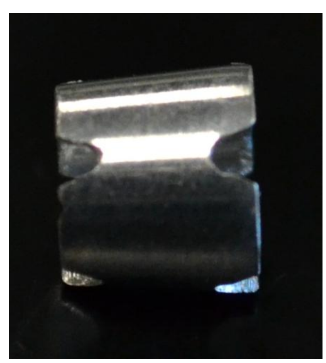

Figure 1 Picture of the Mg-based ring used.

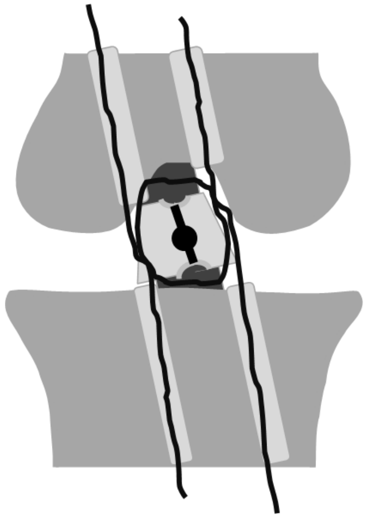

Figure 2 Schematic of surgical technique for implanting ring with goat stifle joint.

RESULTS

The intact ACL had ATT values of 1.9±0.07, 4.0±1.2, and 2.4±0.14 mm at 30, 60, and 90 degrees of knee flexion. ATT values were elevated in the ACL-deficient joint with values of 10.4±1.5, 14.7±0.78, and 13.3±1.2 mm. The values obtained for Mg-based ring repair were improved compared to the values obtained for the ACL-deficient joint at all flexion angles with ATT values of 6.1±0.35, 9.2±0.35, and 7.8±2.1 mm (**Table 1**).

The in situ forces carried in the intact ACL were 62.4±5.1, 64.5±9.2, and 49.5±6.4 N at 30, 60, and 90 degrees. The Mg-based ring repaired ACL also carried appreciable in situ forces at all three flexion angles with loads of 42±8.5, 52±9.9, and 37.5±4.9 N (**Table 2**).

Table 1 ATT data collected from robotic testing for the intact ACL, ACL-Deficient joint, and ACL repaired with the Mg-based ring in response to a 67 N anterior tibial load (mm)

ATT (mm)			
	Intact ACL	**ACL-Deficient**	**Mg-based Ring**
30 ^{o}	1.9 ± 0.07	10.4±1.5	6.1±0.35
60 ^{o}	4.0 ± 1.2	14.7± 0.78	9.2±0.35
90 ^{o}	2.4 ± 0.14	13.3± 1.2	7.8±2.1

Table 2 In situ force in the intact ACL and ACL repaired with the Mg-based ring in response to a 67 N anterior tibial load at three flexion angles in N.

In Situ Force (N)		
	Intact ACL	**Mg-based Ring**
30 ^{o}	62.4±5.1	42±8.5
60 ^{o}	64.5±9.2	52±9.9
90 ^{o}	49.5±6.4	37.5±4.9

DISCUSSION

The objective of this study was to design a Mg-based ring that could load the ACL and reduce ATT, and to develop an implantation technique to attach the ring to a surgically-transected ACL. Both objectives were accomplished, with the design of a Mg-based ring and surgical implantation technique to bridge the gap between the ends of a transected ACL, with ATT and in situ force values obtained from robotic testing showing that repair with the Mg-based ring does decrease ATT at all flexion angles measured and load the ACL. The ATT values measured showed that the ring design and technique should be capable of providing initial joint stability. Furthermore, loading the ACL at time zero with the Mg-based ring should help in preventing degradation of its insertion sites.

The main limitation of this study is that only two goat stifle joints were used. This was done to show feasibility of the design and identify potential design improvements. However, the low numbers of test specimen prevent us from showing statistical significance between the test groups.

Future work in the design of the Mg-based ring will first focus on improving the ring design and implantation, based on observations from this preliminary work. For example, the notches on the ends of the rings were too shallow and it was difficult to secure the sutures within them. The next generation of Mg-based rings will be designed with deeper notches, which should resolve this problem. The choice of sutures is also an important consideration, as it is necessary to obtain secure fixation and mechanical support while avoiding soft tissue damage. Once a design is finalized, the next step will be to conduct an *in vitro* biomechanical study of primary repair of the ACL using the Mg-based ring to measure ATT, in situ force in the repaired ACL, and structural properties of the femur-ACL-tibia complex. Then, an *in vivo* study will be performed to determine the effects of the Mg-based ring on ACL healing.

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I am from Atlanta, Georgia where I attended Westlake High School and The Georgia Institute of Technology. I have always had an affinity for and excelled in mathematics and science. In high school, I had broad academic interests. For example, I studied French and was chief officer for *X-Entertainment, Inc.*, the business formed by my entrepreneurship class which served the school and the surrounding community. Outside of the classroom, I participated in numerous extracurricular activities. The most memorable was being a member of the City of Atlanta Dolphins swim team, with whom I maintained Georgia "All Star" status.

After graduating salutatorian of my high school class, I attended Georgia Tech. I received my Bachelor of Science in Biomedical Engineering, allowing me to apply mathematics and science to create and improve medical devices and processes. A highlight of my undergraduate academic career was my senior project entitled *A Novel Device for the Reconstitution and Administration of Lyophilized Drug Products*. It was a team-oriented design project involving medical device development processes including prior art research, determination of design specifications, consideration of regulatory compliance, 510(k) composition, and prototype development and testing. To supplement my academics, I performed undergraduate research at Georgia Tech in the Laboratory for Neuroengineering and the Muscle Physiology Lab. I also participated in student organizations such as the Women, Science, and Technology Learning community and was involved in community service initiatives including tutoring at the Bellwood Boys and Girls Club of Metro Atlanta.

Upon graduation from Georgia Tech, I continued my academic pursuits as a Bioengineering graduate student at North Carolina Agriculture and Technical State University (NCAT) in Greensboro, NC. This summer research experience at the MSRC has been a perfect fit for me and my interest in biomedical engineering research, product development, and biomechanics. It has also served as a great continuation of the subject area that has been the focus of my studies at NCAT. Not only have I been exposed to subject matter, I have also learned to ask questions, pay attention to details and be proactive in considering research ethics. I would like to thank Dr. Woo, Dr. McCullough, and Kwang Kim for sharing their knowledge and research expertise. I am so appreciative to Dr. Woo and my MSRC family for their support.

COMPARISON OF STRESS DISTRIBUTION PATTERNS WITHIN TRIGONAL, QUADRANGLE, AND HEXAGONAL SCREW DRIVE DESIGNS OF AN ACL INTERFERENCE SCREW USING FINITE ELEMENT ANALYSIS

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INTRODUCTION

The anterior cruciate ligament (ACL) is the most often injured ligament of the knee with well over 100,000 ACL injuries in the U.S. annually [1]. Surgical reconstruction is a widely accepted treatment option and can succeed in restoring joint stability [2]. It is an arthroscopic surgery that involves replacing the damaged ACL with a soft tissue autograft or allograft. Interference screws are used to ensure secure fixation of the graft by compressing it against the wall of the bone tunnel, consequently keeping graft slippage minimal and the graft sufficiently taut.

There are two classes of materials commonly used for ACL interference screws, metallic (i.e. titanium) and bioabsorbable polymers. The ideal interference screw can be described as “best of both worlds” having high mechanical strength, creating a secure initial fixation, being biodegradable, biocompatible, and allowing for osseointegration, and causing no MRI interference. In spite of numerous advances in material development, questions remain about the impact of design on screw performance. This is particularly important with regard to design of the screw head. Stripping/breakage of the screw head or drive was observed in the head of the screw in previous studies [3]. Once a screw is stripped, it cannot be fully inserted, reducing contact area between the screw and the walls of the bone tunnel. Consequently, reducing the ultimate pullout load and increasing graft slippage. The objective of this study was to use finite element analysis to compare three different drive designs (trigonal, quadrangle, and hexagonal) to evaluate stress in the screw head. This can provide critical insight into the causes of the stripping mechanism within the screw drive.

METHODS

Three 3-D computer models of an ACL interference screw were designed in SolidWorks 2010 (SolidWorks Corp., Waltham, MA). These models were 15 mm in length and had a 5 mm outer diameter and a 1.73 mm inner diameter (cannulated). They each had a different drive design in the screw head, a trigonal drive, a quadrangle drive, and a hexagonal drive (Figure 1). The screw geometry was imported into the ANSYS 11.0 (ANYS, Inc., Canonsburg, PA) finite element software. Within ANSYS Workbench, the model was meshed and a static analysis was run to simulate a torque within the drive of the screw. In all the simulations the model was constrained by eliminating all degrees of freedom of the nodes on the outer surface of the screw. In addition, all simulations used Titanium material properties ($E = 9.6E4$ MPa, $\upsilon = 0.36$) with a 2.5 Nm torque applied within the screw’s drive. The model with the trigonal drive design had 6008 nodes and 2957 elements, the model with the quadrangle drive design had 5771 nodes and 2800 elements, and the model with the hexagonal drive design had 5493 nodes and 2586 elements. The monitored outputs were shear and von Mises’ stress distribution within the drive design of the screw head.

RESULTS AND DISCUSSION

The maximum shear stress and maximum von Mises’ stress were observed in the corners of the drive design, an example of the von Mises stress is seen in (Figure 1). The trigonal drive design had a maximum shear stress of 122.48 MPa and a maximum von Mises’ of 212.16 MPa. The quadrangle drive design had a maximum shear stress of 81.627 MPa and a maximum von Mises’ of 141.38 MPa. The hexagonal drive design had a maximum shear stress of 79.47 MPa and a maximum von Mises’ of 137.65 MPa.

From these results, the maximum stress values of the quadrangle and hexagonal drive designs were similar, while the trigonal drive designs stress values were greater. It also appears like the stress has a greater distribution for the hexagonal drive design which has the greatest surface area.

CONCLUSIONS

In order to eliminate insertion failure of ACL interference screws due to stripping and breaking, it is necessary to decrease the maximum stress values and increase the stress distribution. This can be done with drive designs that have greater contact area with the screw driver. Future studies could investigate other screw drive designs such as the torx, turbine, and trilobe drive designs.

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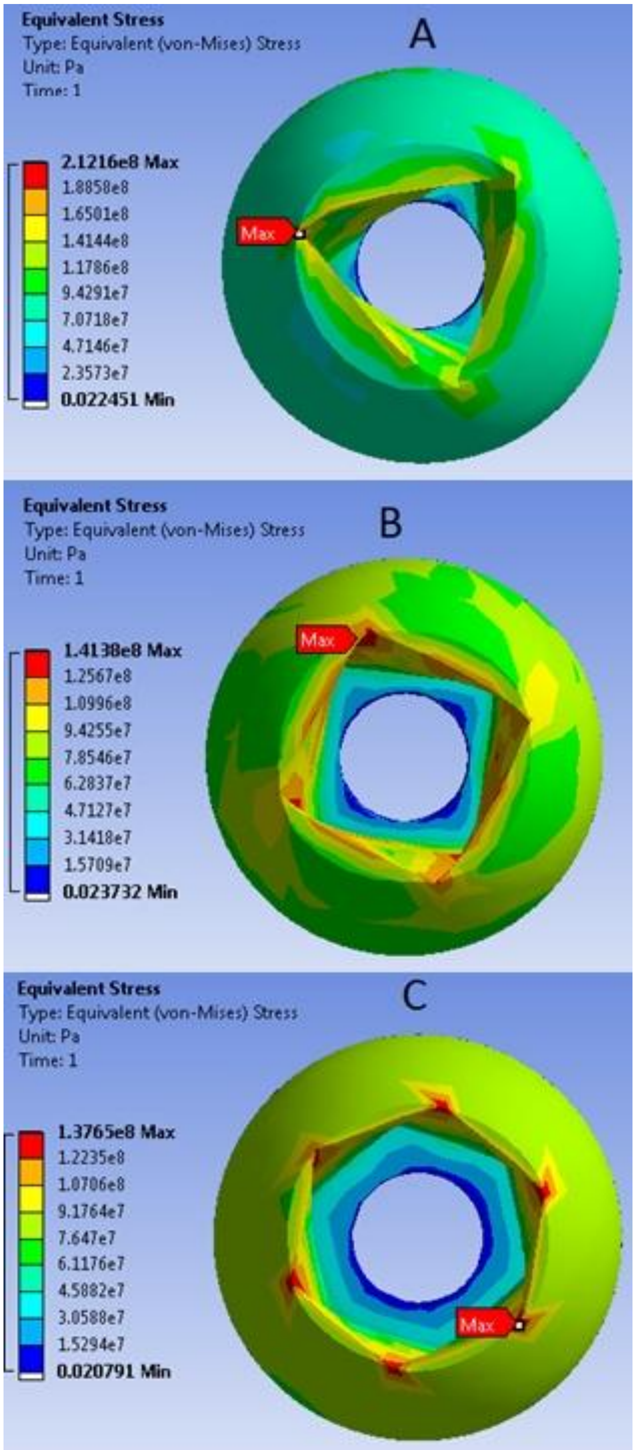

Figure 1: Von Mises Stress Results
A. Trigonal Drive Design B. Quadrangle Drive Design C. Hexagonal Drive Design

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I was born July 15, 1991 and have lived my entire life in Irwin, Pennsylvania, located 45 minutes southeast of Pittsburgh, with my parents and two brothers. I graduated from Hempfield Area High School, where I participated in various clubs and activities such as National Honor Society, Spanish Honor Society, and Interact Club. In addition, I spent a great deal of time volunteering at Excela Health, a hospital system in my area, and I continue to do so whenever time allows. While my extracurricular activities gave me an insight into my future, the stimulating classes I took throughout high school, especially in math and science, truly sparked my interest in engineering and medicine.

I chose the University of Pittsburgh because of its strong bioengineering program and proximity to an advanced medical community. Also, I love living just a bus ride away from the diversity that Pittsburgh offers. In the free time that the bioengineering curriculum affords, I actively participate in the Society of Women Engineers. As the Outreach Chair, I work with organizations such as Girl Scouts of America to promote women in engineering. I also volunteer at UPMC Shadyside and act as an undergraduate teaching assistant in the Department of Chemistry

I began volunteering at the MSRC in 2010 and am thankful to have had the opportunity stay in the lab. Previously, I had no research experience, but my time here has taught me so much. Not only have I learned about ACL reconstruction, the pros/cons of various interference screws, and biomechanical testin g, but also I have gained a better understanding of the research process in general. I would like to thank Dr. Woo for welcoming me into his lab, sharing his talents, and providing words of wisdom that extend far beyond ACL research. Also, I want to thank Kwang Kim for his guidance and for teaching me to become a more independent thinker. Lastly, I express my gratitude to Dr. Andrea Speziali for performing the reconstructions and helping me with the biomechanical testing.

TIME-ZERO EVALUATION OF MAGNESIUM-BASED INTERFERENCE SCREWS

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ABSTRACT

Interference screws are commonly used to firmly affix the ACL graft within the bone tunnel in ACL reconstruction. Currently, interference screws made of metals or polymers are available commercially. Unfortunately, these devices have several shortcomings. With new findings in materials science, magnesium (Mg) as a biodegradable metallic material is gaining more attention, and it is believed that Mg-based interference screws could overcome complications associated with the current options. This study compared the time-zero fixation of Mg-based interference screws when used in ACL reconstructive surgery to affix a bone-patellar tendon-bone graft with that of titanium screws. ACL reconstruction was performed on three (3) pairs of skeletally immature cadaveric goat stifle joints, and either Mg-based or titanium interference screws were used to provide graft fixation. Following reconstruction, the specimens were dissected, and tensile testing was performed on the femur-graft-tibia complex (FGTC). A series of three cyclic creep tests were performed to determine the total elongation of the FGTC, and a load-to-failure test was used to obtain the stiffness and ultimate load of the complex. The total elongations of the Mg-based and titanium screw groups were 1.2 ± 0.8 mm and 1.3 ± 0.6 mm, respectively. The stiffness was 45.6 ± 3.9 N/mm for the Mg-based screw group and 43.2 ± 3.5 N/mm for the titanium screw group. Lastly, the ultimate load values were 327 ± 188 N and 272 ± 31 N for the Mg-based and titanium screw groups, respectively. No significant difference exists between the two screw groups in terms of the obtained parameters, indicating that Mg-based interference screws provide initial fixation comparable to titanium interference screws when used in ACL reconstruction.

INTRODUCTION

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments in the knee. Over 100,000 cases occur annually in the United States alone, and most are due to work and sports-related activities [1]. ACL injuries cause translational and rotational knee instability which may lead to damage in surrounding soft tissues, especially the menisci [2]. Furthermore, midsubstance tears have a low capacity for healing [3]. Therefore, the current treatment for an ACL injury is a reconstruction where a graft, usually the patellar tendon or hamstring tendon autograft, is used to replace the injured ligament and attempt to restore knee joint stability [4]. Interference screws are used during ACL reconstruction to firmly affix the graft within the bone tunnel.

Currently, surgeons use interference screws comprised primarily of metals (stainless steel and titanium alloys) or polymers (polyesters). Metallic screws are widely used because they provide secure graft fixation and have a low occurrence of breakage and acceptable biocompatibility [5, 6]. However, because metallic screws are permanent, they complicate revision surgeries, and their removal requires additional surgeries [7]. In addition, metallic implants often distort images on MRI scans, which impede a physician's ability to administer follow-up care [8].

In an attempt to overcome the complications associated with metallic screws, biodegradable polymer screws have been implemented. Unlike their metallic counterparts, the screws degrade in the body and have no effect on MRI images [9]. However, their degradation rate is not well-controlled, with some screws showing limited degradation after 3 years of insertion [10]. Additionally, polymer screws exhibit an increased occurrence of breakage during the reconstruction procedure due to their reduced strength, resulting in risk to patients [11]. They also have poor biocompatibility which can adversely affect osseointegration and result in bone tunnel widening [12].

As a result of problems with current interference screws, the advantages of biodegradable magnesium (Mg)-based screws are being explored. Through the use of various alloying and coating techniques, Mg screws can be designed to degrade at a controlled rate. Upon degradation, the screws are replaced by native tissue, eliminating the need for a fixation device or any additional surgeries to remove the implant [5]. Additionally, in comparison to polymers, Mg alloys have superior mechanical properties, such as greater tensile and compressive strength, Young's modulus, fracture toughness, and ductility, resulting in a reduction of surgical complications associated with breakage [5, 12]. Mg is also already present in the body so the screw's degradation products can be safely absorbed or excreted [13]. In fact, Mg had been shown to enhance bone remodeling [12]. Because of these potential advantages, the goal of our research center is to design a biodegradable Mg-based interference screw as an alternative to the metallic and polymer options.

The objective of this study was to evaluate the time-zero fixation of Mg-based interference screws when used during ACL reconstruction to affix a bone-patellar tendon-bone (BPTB) autograft in a skeletally immature cadaveric goat model. Time-zero fixation was quantified by determining the total elongation, stiffness, and ultimate load of the femur-graft-tibia complex (FGTC). The results were compared to those obtained when titanium interference screws were used to provide graft fixation.

MATERIALS AND METHODS

Three (3) pairs of skeletally immature cadaveric goat stifle joints were used in this study, and the sides were randomly assigned to a Mg-based screw group or a titanium screw group. The specimens were stored at
-20^{o}C and thawed for 24 hours at room temperature before testing. A 5-mm-wide BPTB graft was then harvested from the joint. The ACL was surgically removed, and two tunnels

(6 mm in diameter) were drilled at the tibial and femoral footprints of the ACL. The bone blocks (5 mm in diameter) of the graft were pulled through the tunnels. Either Mg-based or titanium interference screws were used to affix the graft within the femoral bone tunnel; graft fixation on the tibial side was provided by a staple and a suture post.

All of the soft tissue except the ACL graft was dissected from the reconstructed joint, leaving just the FGTC, and a uniaxial materials testing machine (Instron, Model 4502) was used to determine its structural properties. The FGTC was secured to clamps, wrapped in saline-soaked gauze, and anatomically aligned so that a 45^{o} flexion angle existed between the femur and tibia. A 3N preload was applied to the FGTC, and then a series of three cyclic creep tests were performed. Each test loaded the FGTC between two levels for 100 cycles at an elongation rate of 50 mm/min. For the first and third tests, the FGTC experienced loads between 20 and 70 N. In the second test, loads between 20 and 105 N were used. These loads were chosen to mimic forces that an ACL would experience at normal and high activity levels [14]. A 60-minute resting period was allowed between each cyclic test.

Total elongation (mm), which is the permanent elongation of the FGTC as a result of cyclic loading, was determined after the cyclic creep tests in order to evaluate the graft's slippage. The gauge length of the complex after the initial 3N preload was set to 0 mm of elongation. Then after each test and 60-minute recovery, the 3N preload was reapplied, and the gauge length of the FGTC was measured. The total change in gauge length following all three cyclic creep tests represented the total elongation of the FGTC.

After cyclic loading, a load-to-failure test was performed at an elongation rate of 5 mm/min. From the resulting load elongation curve, the stiffness (N/mm) and ultimate load (N) of the FGTC was determined. The stiffness was determined by calculating the slope of the linear region of the curve, and the ultimate load was defined as the load at which the structure failed. Additionally, the mode of failure of each FGTC was noted.

Paired t-tests were used to compare the total elongation, stiffness, and ultimate load of the Mg-based and titanium interference screw groups. Significance was to $p<0.05$.

RESULTS

Successful BPTB reconstructions were performed on and biomechanical data was collected for three (3) pairs of cadaveric goat stifle joints. A summary of the raw data for each specimen tested can be seen in **Table 1**. Upon completion of three cyclic creep tests, the total elongation of the FGTC was 1.2 ± 0.8 mm for the Mg-based screw group and 1.3 ± 0.6 mm for the titanium screw group. Following the load-to-failure test, the obtained stiffness values were 45.6 ± 3.9 N/mm and 43.2 ± 3.5 N/mm for the Mg-based screw group and titanium screw group, respectively. Lastly, the ultimate load of the FGTC was 327 ± 188 N when Mg-based screws were used and 272 ± 31 N when titanium screws were used. During the load-to-failure test, the majority of failures occurred at the midsubstance of the BPTB graft. The paired t-tests revealed that no significant difference existed between the Mg-based and titanium screw groups in terms of total elongation, stiffness, and ultimate load. A comparison of both groups in terms of the parameters collected is shown in **Figures 1-3**.

Table 1 Summary of data collected for 3 pairs of specimens reconstructed with either Mg-based or titanium screws. Total elongation, stiffness, and ultimate load values are listed.

Specimen Number	Total Elongation (mm)	Stiffness (N/mm)	Ultimate Load (N)
Mg-based			
#1	0.8	47.9	504
#2	0.8	41.1	346
#3	2.1	47.7	130
Titanium			
#1	1.9	40.2	275
#2	0.7	47.0	239
#3	1.3	42.5	301

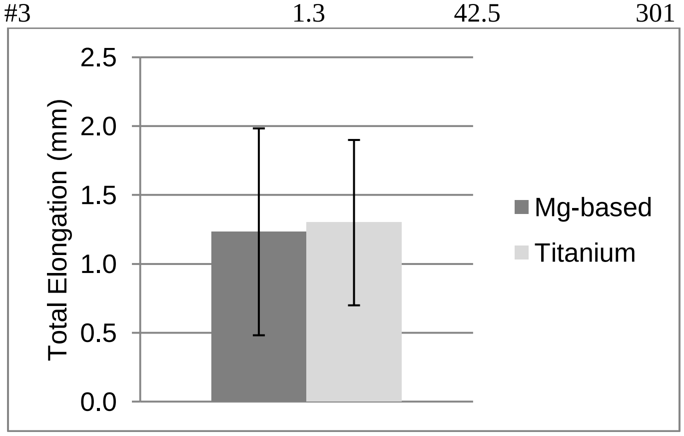

Figure 1. The Mg-based screw group had a total elongation value of 1.2 ± 0.8 mm while the titanium screw group had a value of 1.3 ± 0.6 mm. Standard deviation bars are shown.

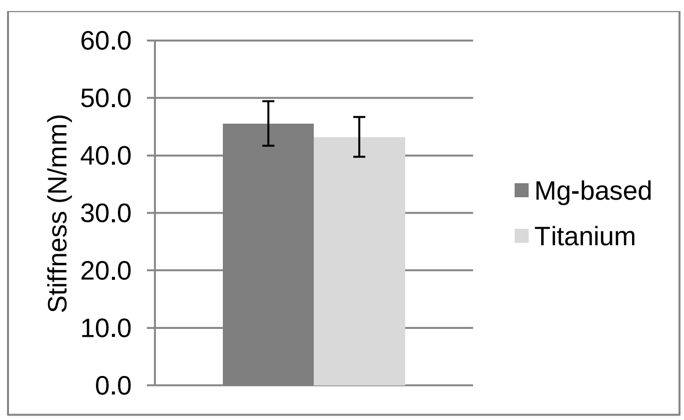

Figure 2. Stiffness was 45.6 ± 3.9 N/mm for the Mg-based screw group and 43.2 ± 3.5 N/mm for the titanium screw group. Standard deviation bars are shown.

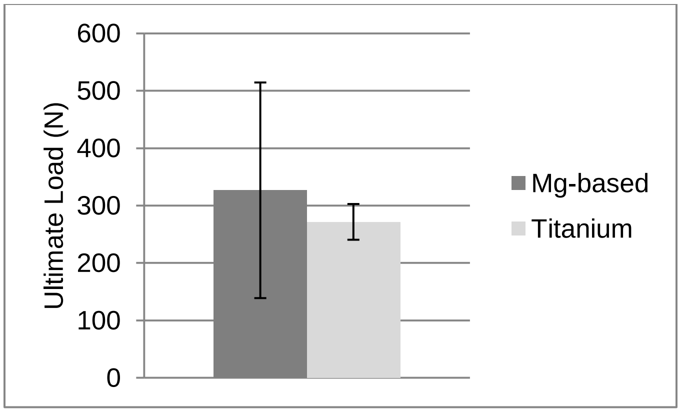

Figure 3. Ultimate load values were 327 ± 188 N and 272 ± 31 N for the Mg-based and titanium screw groups, respectively. Standard deviation bars are shown.

DISCUSSION

The purpose of this study was to compare the time-zero fixation of Mg-based interference screws to that of titanium interference screws. Each screw type was used to affix a BPTB autograft during an ACL reconstruction in a skeletally immature cadaveric goat stifle joint. A series of three cyclic creep tests were used in order to determine the total elongation of the FATC. Since the tibial fixation was a staple and suture post for both test groups, it is assumed that differences in this parameter are a result of the fixation provided by the interference screw. More specifically, the total elongation can help to indicate the slippage of the graft past the interference screw in the bone tunnel. Additionally, during a load-to-failure test, stiffness and ultimate load were determined. These structural properties are another means to evaluate the fixation of the interference screw.

No significant difference was found between the Mg-based and titanium interference screw groups in terms of the total elongation, stiffness, or ultimate load of the FGTC. These results indicate that Mg-based interference screws have a time-zero fixation comparable to that of titanium interference screws when used in ACL reconstruction. The total elongation of the FGTC was similar meaning that the screws provided similar resistance to graft slippage when subjected to loading at time zero. Additionally, the FGTC achieved comparable time-zero structural properties regardless of whether Mg-based or titanium screws were used during the reconstruction. Also, because both groups failed at the midsubstance of the FGTC, it can be concluded that neither screw type is more subject to failure.

A limitation of this study is that a small sample size of skeletally immature specimens was used, which could account for some of the variability in the data collected. Additionally, the data obtained is only at time zero and does not provide information on the fixation of the Mg-based screws during healing and recovery. Lastly, because the study was performed on a goat model, the results may not translate when the screws are used in humans.

Future work will include evaluating the time-zero fixation of the Mg-based interference screw in a skeletally mature cadaveric goat stifle joint in order to reduce some of the variability seen in the skeletally immature specimens. A larger sample size will also be used. Once again, the interference screws will affix a BPTB autograft during ACL reconstructive surgery, and the results will be compared to those obtained when titanium screws are used. Following this in-vitro evaluation, an in-vivo study will be performed to evaluate the fixation of Mg-based screws in a goat model after 12 weeks of healing. The fixation provided at time-zero and after 12 weeks will then be compared.

Based on the results of this study, design improvements will be made to the Mg-based interference screws so that they can eventually replace current interference screw options and improve the outcomes of ACL reconstructions. Not only could this project impact ACL reconstructions, but it also provides a means of examining the potential of using Mg-based implants in other orthopaedic applications that involve the healing of both bone and soft tissue. These findings can be translated to other fixation devices, such as suture anchors and bone pins/screws, for trauma, craniofacial, and pediatric surgeries.

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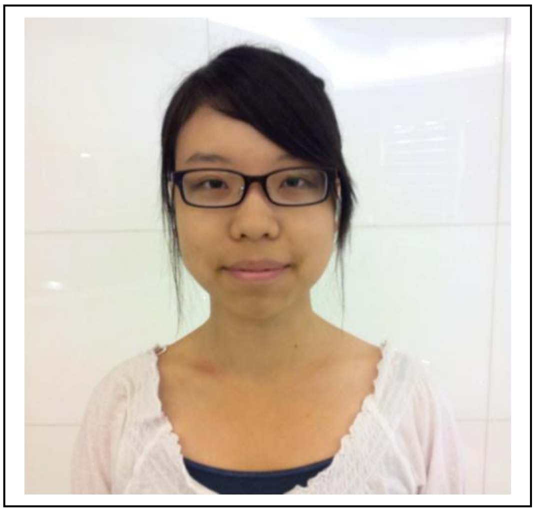

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I was born September 29, 1990. I live in Hong Kong with my parents and my elder brother. I had my secondary education in C.C.C Mong Man Wai College and graduated in 2010. Thanks to the teachers, I have developed my interest in science and mathematics. Besides, I participated in the Social Service Club and the Music society as a committee member. I have organized various activities for the schoolmates. Outside school, I participated in social services at a YMCA youth centre and other organizations in my district. I learned to be more mature from the volunteer experience. I also gained many soft skills through interacting with different people.

I chose the Biomedical Engineering program at the Chinese University of Hong Kong (CUHK), which allows me to study further in applied science. I was equipped with the knowledge in both the biomedical and engineering field. I made my college life enjoyable through involving in various activities. I served as treasurer of the Hong Kong Institution of Engineers Student Chapter –CUHK, which allows me to have a deeper understanding of the engineering field in Hong Kong. Last summer, I helped to organize the orientation camp for Engineering Faculty and my own college. I had the most memorable moment when working hard with the fun people.

Before working at the MSRC, I had only basic knowledge of the knee joint and ACL. I got a better understanding of those while I was working on a project about ACL reconstruction. I also learned to conduct a biomechanical test and use the tools for reconstruction. This was the first time for me to work in a lab. I gained the valuable experience of doing research. I do appreciate the working attitude of the researchers and students in MSRC and the effort they paid to push the research work forward.

I would like to thank Dr. Woo not only for providing the chance for CUHK students to work at MSRC but also for sharing experiences and sayings to enrich our horizons. I would like to express my gratitude to my mentor Dr. Sasaki. He gave me guidance on conducting the research and taught me lots of medical knowledge. I would also like to thank Kwang Kim for his help and advice.

BIOMECHANICAL COMPARISON OF KNEE STABILITY: ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION WITH QUADRICEPS TENDON VERSUS HAMSTRING TENDON

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INTRODUCTION

The anterior cruciate ligament (ACL) is an important ligament maintaining knee stability [1]. The main function of ACL is to resist anterior-posterior tibial translation and internal tibial rotation moments about the knee [2, 3]. Rupture of the ligament causes knee instability as well as secondary damage to the knee and increased risk of osteoarthritis [4, 5]. The incidence rate of ACL injury is very high due to its susceptibility to injury during competitive sports activities. The recent incidence rate of ACL rupture has been reported to between 36.9 and 60.9 per 100,000 person-years.[6,7]

To restore knee function, expedite patient's return to normal activity and avoid long term complications, ACL reconstruction is the preferred treatments for ACL injury. [9, 10] The ideal outcome of ACL reconstruction is to reproduce the characteristic of native ACL. Graft selection would be one of the major factors that affect the reconstruction outcome.

At present, the bone-patellar tendon-bone(BPTB) autografts and the the hamstring (semitendinosus and gracilis tendons) (HT) autografts are the commonly used grafts for ACL reconstruction. Although they restore the knee kinematics and in situ force of ACL, the complications they caused make them not an ideal graft choice. BPTB leads to more severe donor site mobidity including high postoperative anterior knee pain and anterior knee numbness [11-13] while hamstring tendon has the problem with bone tunnel enlargement, graft failure and longer healing time[14,15]. As the problems caused by these two grafts, we would like to seek for alternatives for ACL reconstruction.

Studies shown that the quadriceps tendon could be suitable graft choice, it is not commonly used though. The quadriceps tendon was first reported by Marshall et al. in 1979 and then advocated by Blauth, Staubli et al. Similar to hamstring tendon, it has the advantage of low donor site morbidity. It was also reported to have sufficient amount of substance and mechanical properties for the graft in ACL reconstruction [16-18] with the ultimate load of 2,352 N, which is comparable to the intact ACL [19, 20]. In addition, the cross-sectional area of quadriceps tendon is large that prevents tunnel widening problem caused by hamstring tendon [21].

With the advantages of quadriceps tendon shown, it could be the alternative graft choice for ACL reconstruction. Up to now, there lack test to asses knee stability after ACL reconstruction using quadriceps tendon. In order to investigate the biomechanical performance of knee joint by using quadriceps tendon, our research lab has to perform the in-vitro study.

OBJECTIVE

The objective of this study is to determine if the quadriceps tendon can restore knee kinematics and to compare the biomechanical knee stability after ACL reconstruction with hamstring tendon and quadriceps tendon. The first stage of the project would be doing practice on porcine knee to ensure an appropriate experimental and surgical procedure. The second stage is to do testing on human cadaver knee. The plan for summer would be to finish the first stage.

MATERIALS AND METHODS

Specimen Preparation

Frozen porcine knees were thawed in room temperature 24 hours before testing. The femur and tibia were cut approximately 20 cm from the joint line and the soft tissues were removed approximately 10 cm away from the joint line, leaving the joint intact. The specimens are kept moist with 0.9% saline solution.

Testing System and Set Up

Femur and tibia are secured with custom made aluminum cylinders by using an epoxy compound (Fibre Glass-Evercoat, Cincinnati, Ohio) with transfixing bolts. Then it is mounted in a robotic /Universal Force Moment Sensor (UFS) testing system. Femur is rigidly fixed relative to the base of the robotic manipulator (KR120, KUKA Robots, Augsburgh, Germany) and tibia is attached to the end effecter of the robotic manipulator through the UFS (Model 4015, JR3 Inc, Woodland Hills, California). The robotic manipulator is used to apply and record certain loading conditions to the specimen. It has a position and orientation accuracy and repeatability of less than 0.1 mm and 0.1° respectively. The UFS measured 3 forces and 3 moments in a Cartesian coordinate system with respect to the sensor.

Testing Protocol

Bone-patellar tendon-bone grafts (BPTB) were used in porcine model as the hamstring tendon and quadriceps tendon are not suitable for reconstruction in porcine model. The experimental protocol is shown in **Table1**. The passive path of the intact knee from 45° to 90° was determined first. Then two loading conditions were applied to the knee: (1) a 89 N anterior tibial load at 45°, 60° and 90°, of flexion of the knee; and (2) a combined 100 N axial and 89 N anterior tibial load at full 45°, 60° and 90° of knee flexion.

The 5 DOF kinematics of the intact knee were recorded corresponding to the loading conditions at each flexion angle. Next, the ACL of the knee was transected. The 5 DOF kinematics recorded previously was repeated with the ACL deficient knee. The forces and moments were recorded by the UFS. The in situ force of ACL would be the vector difference in forces between intact knee and the ACL deficient knee. Same loading conditions were reapplied to ACL deficient knee to obtained kinematics. ACL reconstruction was performed. The loads were then reapplied to the reconstructed knee, and the resulting kinematics were recorded. The corresponding kinematics is repeated after releasing the grafts. Finally, the data obtained would be the in situ force of ACL and the bone-patellar tendon-bone grafts as well as the kinematics data at each status of the knee, i.e. the intact, ACL deficient and the reconstructed knee. It is the resultant force of the force difference in three directions.

The data were analyzed by using a two-factor repeated-measures analysis of variance. Significance was set at $P < 0.05$.

Table1. Experimental protocol

Status of Knee	
1. Intact	Path of passive extension/flexion
	Apply load
2. ACL deficient	Apply load
	Repeat kinematics of intact knee
3. With BPTB graft	Apply load
	Release suture and repeat kinematics of BPTB reconstructed knee

Surgical Technique

Tibial and femoral funnels were placed in a routine fashion using commercially available drill guides (Tibia: Protrac; Smith&Nephew, Andover, MA ; Femur: 7-mm offset guide; Arthrex, Naples, FL). Tibial tunnel is located in the anteriormedial bundle insertion site. Femoral tunnel is located at the 11 o'clock (right knee) or 1 o'clock (left knee) using a 7-mm offset drill guide by transportal technique, assuring that the posterior edge of the femoral tunnel was placed 2mm anterior from the posterior edge of the intercondylar notch. The graft is passed through the tibial and femoral tunnels. A titanium interference screw (RCI screw ® Smith & Nephew Inc, Mansfield, Massachusetts) was used for femoral side graft fixation. Graft is preconditioned by moving the knee between full extension and 90° of knee flexion. Posterior tibial load is applied at 30° of knee flexion and 44 N of initial graft tension is maintained for graft fixstion. The graft is secured with spiked plate and staple (Mitek, Smith & Nephew Inc, Mansfield, Massachusetts).

After testing, the bone tunnels on tibia and femur were checked to confirm the position is correct.

RESULTS

Complete data for ACL reconstruction using BPTB have been obtained from three porcine knees. Biomechanical data for the specimens (n=3) under two loading conditions was collected and shown in **Figure 1** and **Figure 2**. The anterior tibial translation (ATT) for anterior tibial load of reconstructed knee (7.3±0.6, 7.1±0.9 and 5.5±1.8 mm) was slightly higher than that of the intact knee (5.8±1.1, 5.7±1.3 and 3.4±1.4 mm) at both 45° ,60° and 90° of knee flexion. Comparing with the intact and reconstructed knee, the ATT of ACL deficient knee was obviously larger (12.4±2.2, 12.8±1.3 and 8.5±1.6). Under the combined load, the difference in ATT difference between intact and ACL deficient knee is similar. One of the specimens was excluded for the combined load as large ATT deviation appeared due to minor bone breakage at tibia.

The in situ force of ACL/BPTB graft is calculated from the apply force data for intact/reconstructed knee and the force recorded when kinematics is repeated. They are shown in **Figure 3** and **Figure 4**. Under single anterior tibial load, the in situ force of BPTB graft at 45° ,60° and 90° knee flexion was 100.6±8.3, 92.0±7.2 and 74.0±12.1 N while it was 88.4±8.3, 86.0±7.3 and 58.0±12.1 N for intact knee. Under combined axial and anterior tibial load, the in situ force of BPTB graft at 45° ,60° and 90° knee flexion was 124.2±15.5, 125.4±12.6 and 104.8±13.9 N respectively. And that of intact knee was 90.2±28.4, 144.1±12.6 and 105.8±12.9 N respectively.

Figure 1 Anterior Tibial Translation in Response to a 89 N Anterior Tibial Load

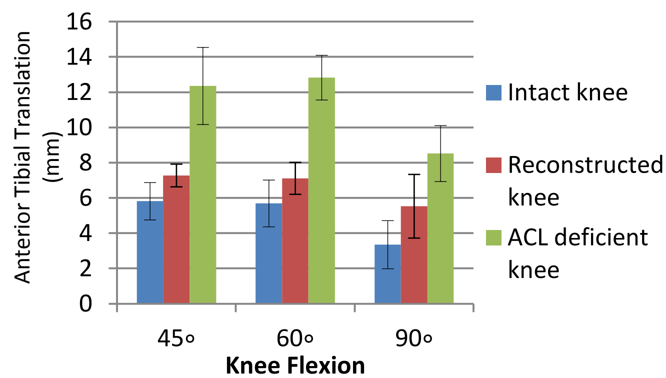


Figure 2 Anterior Tibial Translation in Response to a Combined 100 N Axial and 89 N Anterior Tibial Load

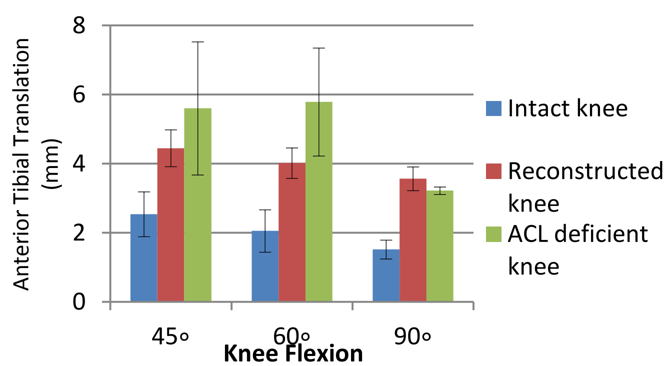


Figure 3 In Situ Force in ACL and the BPTB graft under 89 N Anterior Tibial Load

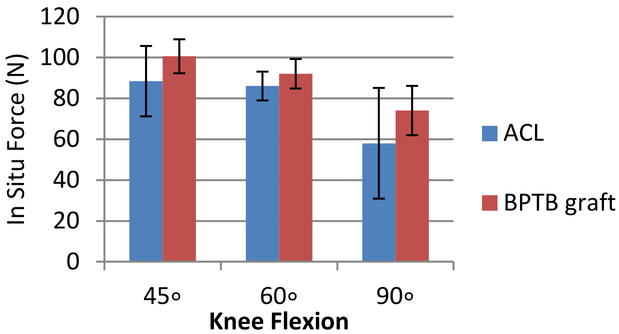
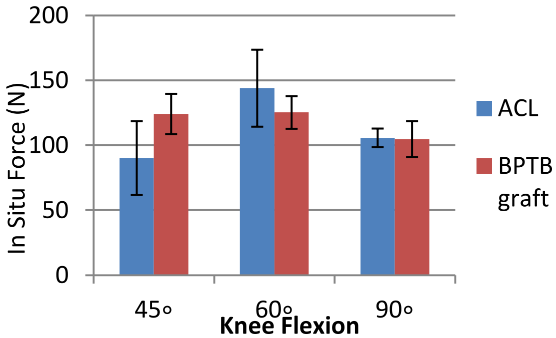


Figure 4 In Situ Force in ACL and the BPTB graft under a Combined 100 N Axial and 89 N Anterior Tibial Load



DISCUSSION

The purpose of the porcine knee test is to do practice for real testing on human knee. Therefore, the testing procedure, surgical method, tools adopted and robotic setting should be confirmed beforehand. The biomechanical data obtained is important to determine whether the procedures and settings are appropriate. The ATT under anterior tibial load for intact and ACL deficient knee is comparable to past data from literature [22]. As the sample size is too small, statistical significance cannot be obtained among different knee status. Data obtained would be more affected by natural difference among specimens.

By direct comparison, the ATT for reconstructed knee is smaller than that of ACL deficient knee and similar to intact knee, which implies that the reconstruction could restore knee kinematics under this condition. For the combined load, there is no existing data that could be compared with. The ATT difference between intact and deficient knee is larger comparing with that under single anterior tibial load. At 90°, ATT of reconstructed knee is higher than the ACL deficient knee. One possible reason for it may be a higher graft tension is required for combined axial compressive and anterior tibial load. During compression, the insertion sites of the graft at tibia and femur may be closer and made the graft loosen. Higher initial graft fixation tension could be tried to ease the problem.

In both conditions, the in situ force of BPTB graft has comparable or superior result comparing with that of the ACL. The BPTB graft could restore the in situ force of ACL.

Besides, using porcine knee could not perfectly model human knee. First, as the resistance for internal tibial rotation is too small on porcine model, it can only be tested in four degree of freedom. The condition of combined internal tibial torque and valgus torque for human knee protocol cannot be tested. Second, porcine model can only provide BPTB graft for reconstruction, which has different structure and anatomical position from hamstring tendon and quadriceps tendon. The surgical technique required is also different with using BPTB during graft harvesting and reconstruction. Attention must be paid during graft harvesting, bone tunnel positioning and graft fixation. As the soft tissues are easily injured, they should be handled with care. It would be better to have practice test on human cadaver knee before real testing.

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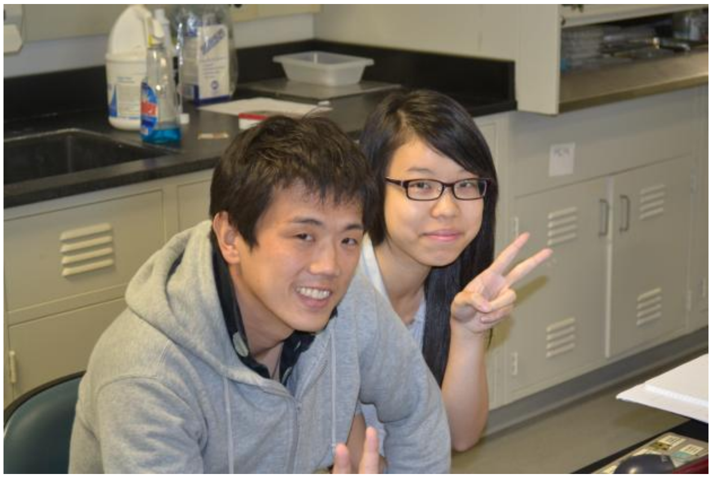
A Summer at the MSRC



Ching and Nori working on the robot

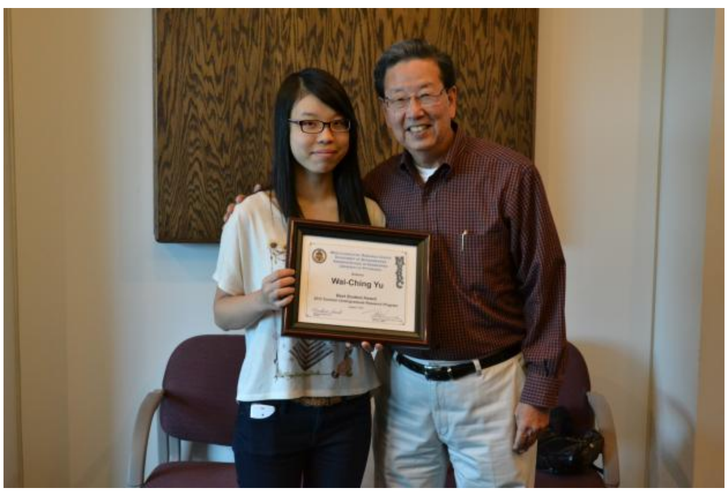
Andrea with the ladies of the lab

The summer interns with Dr. Woo

A Summer at the MSRC

Attempting a jumping picture…

…which obviously was not successful



Congratulations Ching!

Relaxing at the end of the symposim

Group picture of the lab on a beautiful day

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