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已取得研究成果（论文、专利、获奖等）	**论文题目**	**本人排名**	**发表年月**	**期刊（会议）名称**	**被检索类型**	
	The Use of a Large Animal Model and Robotic Technology to Validate New Biotherapies for ACL Healing	2	2017.05	Bio-orthopaedics	著作/书	
	Influence of Different Boundary Conditions in Finite Element Analysis on Pelvic Biomechanical Load Transmission	3	2017.02	Orthopaedic Surgery	SCI	
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The Use of a Large Animal Model and Robotic Technology to Validate New Biotherapies for ACL Healing

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Jonquil R. Mau, Huizhi Wang, and Savio L-Y. Woo

Contents

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15.1 Introduction

The anterior cruciate ligament (ACL) is a major knee stabilizer and also the most frequently injured. In the United States alone, there are over 150,000 isolated ACL injuries and an additional 50,000 combined ACL and medial collateral ligament (MCL) injuries that occur annually. It is also generally known that midsubstance ACL tears do not heal well. If left untreated, it could cause chronic knee instability and damage to secondary stabilizers, especially the meniscus that could lead to early onset of osteoarthritis [1]. Historically, primary suture repair had been tried to reconnect the torn ends of the ACL to encourage its healing but with poor clinical outcome [2–4]. As a result, surgical reconstruction by means of soft tissue replacement grafts (ACL reconstruction) has become the treatment of choice as this procedure could provide initial joint stability and improved knee function [5].

While the results of ACL reconstruction have been excellent especially in the short term, long-term follow-up on patients at 10 years or more postsurgery has shown that up to 25% had unsatisfactory results that include graft donor site morbidity, residual knee pain, and prevalence of osteoarthritis [6–8]. These complications have also prompted the development of a large number of surgical techniques and a variety of postoperative rehabilitation protocols.

In recent years, alternative approaches to heal the injured ACL by means of biotherapies

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BASIC RESEARCH

Influence of Different Boundary Conditions in Finite Element Analysis on Pelvic Biomechanical Load Transmission

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Objective: To observe the effects of boundary conditions and connect conditions on biomechanics predictions in finite element (FE) pelvic models.

Methods: Three FE pelvic models were constructed to analyze the effect of boundary conditions and connect conditions in the hip joint: an intact pelvic model assumed contact of the hip joint on both sides (Model I); and a pelvic model assumed the hip joint connecting surfaces fused together with (Model II) or without proximal femurs (Model III). The model was validated by bone surface strains obtained from strain gauges in an *in vitro* pelvic experiment. Vertical load was applied to the pelvic specimen, and the same load was simulated in the FE model.

Results: There was a strong correlation between the FE analysis results of Model I and the experimental results (R^2 = 0.979); meanwhile, the correlation coefficient and the linear regression function increased slightly with increasing load force. Comparing the three models, the stress values in the point near the pubic symphysis in Model III were 48.52 and 39.1% lower, respectively, in comparison with Models I and II. Furthermore, the stress values on the dome region of the acetabulum in Models II and III were 103.61 and 390.53% less than those of Model I. Besides, the posterior acetabular wall stress values of Model II were 197.15 and 305.17% higher than those of Models I and III, respectively.

Conclusions: These findings suggest that the effect of the connect condition in the hip joint should not be neglected, especially in studies related to clinical applications.

Key words: Biomechanics; Finite element analysis; Pelvis

Introduction

The pelvis, as the center of a musculoskeletal biomechanical system, facilitates transfer of weight from the upper part of the body to the lower extremities. The resultant force through the hip joint during walking is around three times greater than body weight, and may be up to six times greater than body weight during running and stair climbing[1,2]. Thus, the reconstruction of pelvic comprehensive biomechanics after an injury is the primary consideration of clinical management. Various implants have been utilized in the management of pelvic injuries, such as reconstructive plates, dynamic compression plates, locking plates, lag screws, and sacral rods[3]. Generally, the clinical efficacy and biomechanical features of the implants used for pelvic injuries should be evaluated through biomechanical experiments *in vitro*. However, irregular geometry and material heterogeneity of the pelvis often make mechanical experiments challenging[4]. In the past decade, the finite element (FE) analysis method has

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DEVELOPMENT AND VALIDATION OF A 3-D FINITE ELEMENT MODEL OF GOAT STIFLE JOINT

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RATIONALE

Novel functional tissue engineering approaches have enabled successful healing of a torn anterior cruciate ligament (ACL) [1-3]. In our research center, we have used an innovative magnesium (Mg) ring device to improve ACL healing in a goat model [3, 4]. This success begs the question on the stress and load levels in tissues of interest. As such, an accurate computational model of a goat stifle joint would help to better understand how the Mg ring works as mechanical augmentation. With this data, we can develop success criteria and use them to guide the design of devices for human ACL repair.

METHODS

A realistic three dimensional (3D) finite element model of a goat stifle joint was built from MRI images (Figure 1). Bones, cartilages, meniscus and ligaments were included. Geometric dimensions including the width of ligaments, the width of femoral notch and the height of menisci were measured in Creo 2.0 and compared with experimental measured data using the same joint. A total of 130144 tetrahedral elements were used to segment the model. Kinematics of the goat stifle joint at different joint flexion angles (30°, 60°, 90°) under a 67-N anterior tibial load obtained previously in our research center were used as boundary conditions for the model calculating [4]. Calculated in situ forces in the ACL were then compared to those obtained experimentally for validation of the model.

RESULTS AND DISCUSSIONS

Geometric differences between computational and experimental measurement were found to be within 1 mm (Table 1). The in situ forces in the ACL under different joint flexion angles as calculated by the model had a difference less than 7.5 N to those obtained from robotic testing (Table 2). Thus, the model is anatomically and kinematically validated. In the future, we will scale the model up to mimic the human knee and use the results of this study to guide the design of the Mg devices for the human ACL.

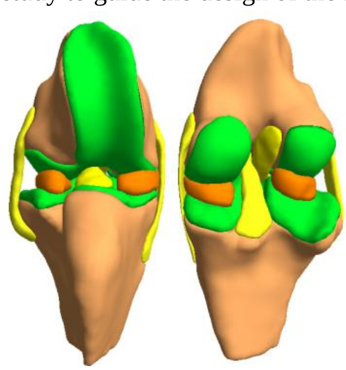

Fig1. 3D model of goat stifle joint

Table 1 Geometrical data from stifle joint model and experimental measurement (mm)

	ACL width	Notch width	MM height	LM height
Experimental	5.6	7.6	4.4	3.9
Computation	6.1	8.0	5.2	4.5
Difference	0.5	0.4	0.8	0.6

Table 2 ACL in situ force from model calculation and robot testing

Joint flexion (°)	30	60	90
ACL force from robot testing (N)	71.8	76.9	68.8
ACL force from model calculating (N)	61±8	59±4	51±9
Difference (N)	7.2	-0.1	-5.1

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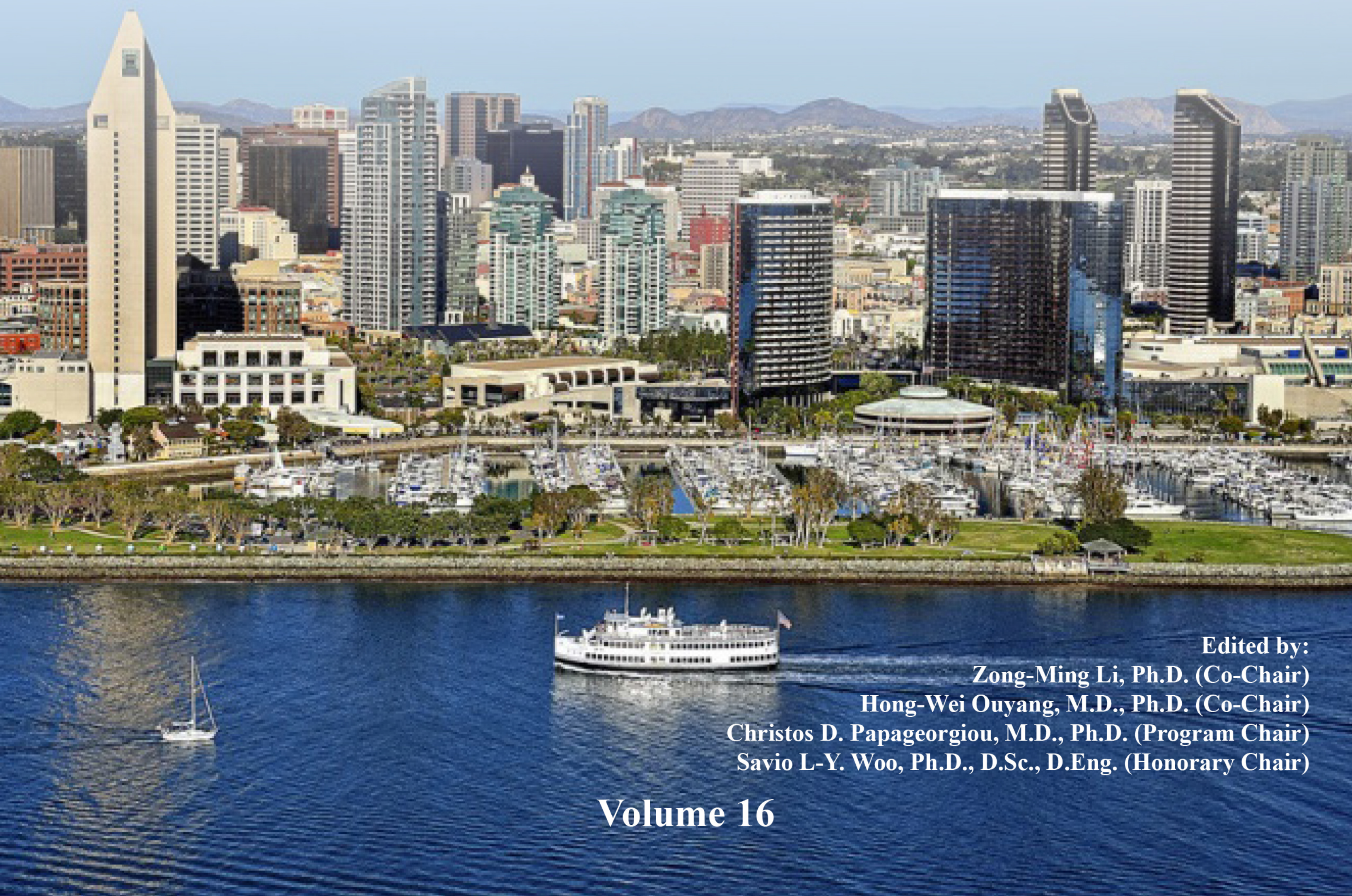

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FINITE ELEMENT ANALYSIS OF JOINT STABILITY AND ACL LOAD FOLLOWING MECHANICAL AUGMENTATION FOR GOAT ACL HEALING

Huizhi Wang[1,2], Jonquil R. Mau[2], Huijun Kang[2], Jie Yao[1], Cheng-Kung Cheng[1], and Savio L-Y. Woo[2]
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INTRODUCTION

In a previous study, we have shown that a novel magnesium (Mg) ring device could improve ACL healing in a goat model [1]. Such mechanical augmentation could restore joint stability and simultaneously load the ACL and its insertion sites [2]. The objective of this study was to develop a computational finite element model of goat stifle joint in order to determine load in the ACL and stress distribution on it following ring repair surgery in order to better understand how the novel Mg ring device performed as mechanical augmentation.

METHODS

A three dimensional (3D) finite element model of a mature goat stifle joint was built from MRI images (Figure 1) [3]. Geometric dimensions were measured experimentally using electric calliper and compared with those measured in the computational model. Anterior-posterior tibial translation (APTT) and load in the ACL under a 67-N anterior-posterior tibial load (APTL) were calculated and compared with robotic testing data to validate the model. A 67-N APTL was then applied at 37°, 60° and 90° of joint flexion at three joint states: ACL intact, ACL deficient and after ring repair. APTT was calculated and compared with results from previous *in vitro* study. Load in ACL and maximal effective stress at its femoral insertion after ring repair surgery were then explored.

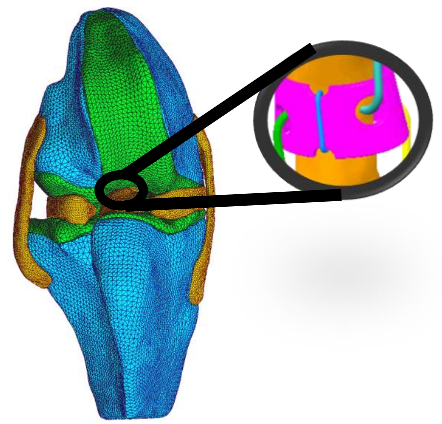

Figure 1. 3D Model of Goat Stifle Joint & ACL with Ring Repair

RESULTS

With a relative high resolution of MRI (0.1 mm), differences of geometric dimensions between computational and experimental measurements were within 1 mm. Meanwhile, calculation differences of APTT and load in ACL were validated to be within 0.3 mm and 5 N, respectively. With ACL deficient, calculated APTT increased to more than twice that of the intact joint. After ring repair, APTT was reduced by around 50% from ACL deficient state (Table1), showing a well consistency with previous *in vitro* study. Load in ACL after ring repair was restored to 46-60% of intact ACL, while the maximal effective stress at femoral insertion was restored to 39-71% that of the intact joint state (Table1).

Table1. Anterior-Posterior Tibial Translation, Load in ACL and Maximal Effective Stress at Femoral Insertion

	APTT (mm)			Load in ACL (N)			Maximal Effective Stress at Femoral Insertion (MPa)		
Joint Flexion	37°	60°	90°	37°	60°	90°	37°	60°	90°
ACL Intact	4.4	3.7	2.7	67	79	68	15.2	25.5	59.9
ACL Deficient	10.6	9.0	5.2	--	--	--	--	--	--
Ring Repair	5.2	4.4	2.9	31	38	41	9.8	10.0	42.6

DISCUSSION

A 3D computational model of a goat stifle joint was built. It was then validated with the published results from an in vitro study. Restored APTT after ring repair implicates good joint stability immediately after surgery which is important for the following healing of the ligament. Stresses at ACL femoral insertion could reduce the risk of disuse atrophy. Further, the loads in the repaired ACL and stress distribution at femoral insertion can now be used in a model of the human knee as a basis for Mg device designs for ACL repair.

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Date: Friday, February 16, 2018 at 4:22 PM
To: Savio Woo <slyw@pitt.edu>, Huizhi Wang <wang_huizhi8866@163.com>, Jonquil Mau <jonquil.flowers@gmail.com>
Subject: ISL&T-XVII Abstract Acceptance

Dear Dr. Woo,

Congratulations! The International Program Committee is delighted to accept your abstract entitled "Finite Element Analysis of Joint Stability and ACL Load Following Mechanical Augmentation for Goat ACL Healing" as a **5-minute podium** presentation for ISL&T-XVII.

We are requesting an acknowledgement of acceptance and the name of the presenter to be submitted to us by **Wednesday, February 28th**, along with the presenting author's registration form, if not already submitted, (copy attached and can be found at www.pitt.edu/~msrc).

Slides are to be prepared in **PowerPoint format** and presentations are limited to a maximum of **5 slides**. Please remember that this audience is already familiar with the background on ligaments and tendons. Thus, in-depth introductory material is not necessary. Shortly we will provide you with instructions o

how to submit your presentations. Your presentation will be due to us on **Friday, April 6th**

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锁骨接骨板预弯塑形的生物力学研究

彭远来[1]，马新硕[1]，危紫翼[1]，杨展宗[2]，李　梅[3]，霍尔凡[3]，朱保璋[3]，祁昕征[1]，王慧枝[1]，郑诚功[1,2]

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摘要:目的　比较解剖型锁骨板与重建型锁骨板的生物力学特性,并探究预弯塑形及反复弯制对重建型锁骨板生物力学性能的影响,为临床治疗锁骨中断骨折提供生物力学依据。**方法**　依据解剖型锁骨板的形状对重建型锁骨板分别进行 1、2、3、5 次的弯制,通过静态压缩实验测试并比较各组试件的生物力学差异性。**结果**　① 解剖型骨板固定刚度和强度显著优于重建型未弯制骨板。② 人工预弯一次后的重建型骨板与解剖型骨板间固定刚度和强度差异不明显。③ 弯制对骨板力学性能有较大影响,且弯制一次后骨板固定刚度和强度明显提高。④ 骨板仅弯制一次后再弯制会明显降低骨板的力学性能。**结论**　与锁骨贴合度更高的解剖板和弯制一次的解剖形重建板与未塑形重建板相比固定刚度和强度更佳。建议术者在使用重建型锁骨板进行骨折固定手术时,应根据患者锁骨解剖形态进行适当的预弯塑形,并尽量减少重复弯制次数,以维持骨板的刚度与强度。

关键词:解剖型锁骨板；骨折；预弯；生物力学

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Biomechanical Study on Pre-Bending for Clavicle Plate

PENG Yuanlai[1], MA Xingshuo[1], WEI Ziyi[1], YANG Zhanzong[2], LI Mei[3], HUO Erfan[3], ZHU Baozhang[3], QI Xinzheng[1], WANG Huizhi[1], ZHENG Chenggong[1,2]

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Abstract: Objective　To compare biomechanical properties between anatomical clavicle plate and reconstructed clavicle plate, and investigate the influence of pre-bending or repeated bending process on biomechanical properties of the reconstructed clavicle, so as to provide biomechanical evidence for treating midshaft clavicle fracture in clinic. **Methods**　The reconstructed clavicular plate was bent by 1, 2, 3, 5 times respectively based on shape of the anatomical clavicular plate. The biomechanical differences in anatomic plate group, reconstructed plate group and pre-bending plate group were compared by static compression test. **Results**　① The fixation stiffness and strength of the anatomical plate were better than those of the reconstructed plate. ② There was no significant difference in stiffness and strength between the anatomical plate group and one-time bending group. ③ Pre-bending had a great effect on mechanical properties of the bone plate, and stiffness and strength of the bone plate were obviously improved after one-time bending. ④ The mechanical properties of the bone plate were obviously reduced by bending of the bone plate after one-time bending. **Conclusions**　The stiffness and strength of the ana-

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