6. Summary

6.1 Introduction

In this dissertation, the effects of graft pretension in anterior cruciate ligament (ACL) reconstruction were investigated in a series of projects. Both in vitro and in vivo models were used to gain a better understanding of the issues at hand. The restoration of intact knee kinematics using the intrinsic ACL as an ideal graft was analyzed. Porcine knee kinematics were described and compared to human knee kinematics. The mechanical characteristics of porcine patellar tendons were ascertained. Finally, a load cell/telemetry system was developed to investigate the load history of grafts and the effects of pretension under in vivo conditions.

6.2 Conclusions

6.2.1 Restoration of Knee Kinematics

Based on this study, the following conclusions were made:

1) It may not be possible to restore intact knee kinematics after releasing the tibial insertion site of the ACL.

2) Current graft tensioning techniques may not allow the restoration of intact knee kinematics.

3) The pretensions that best restore intact knee kinematics may fall into a wide range across the general population.

4) Considering only one kinematic variable when trying to restore intact knee kinematics may not be sufficient.

6.2.2 Porcine Knee Kinematics

Based on this study, the following conclusions were made:

1) The ACL limits anterior translation of the tibia in both species

2) The ACL limits internal rotation of the tibia in humans and external rotation of the tibia in pigs.

3) Differences in kinematic patterns for internal/external rotation and abduction/adduction between the species may be explained by requirements for biped and quadruped stances.

4) The pig is an acceptable model for in vivo studies of ACL reconstruction.

6.2.3 Mechanical Characteristics of Porcine Patellar Tendons

Based on this study, the following conclusions were made:

1) Both strain rate and skeletal maturity affect the mechanical characteristics of porcine patellar tendons.

2) To more reliably obtain a midsubstance failure during mechanical testing of porcine patellar tendons, elongation rates of 200 mm/min or faster should be used. Midsubstance failures are also more likely if tendons from skeletally mature animals are used.

3) The failure mode of a tendon or ligament may be affected by anatomy, and hence may be species-dependent for a given tissue.

4) Differences in stress relaxation behavior between tendons from skeletally mature and immature animals may be attributed to presumed differences in water content.

6.2.4 In Vivo Graft Pretension Effects

Based on this study, the following conclusions were made:

1) The load cell/transmitter system is suitable for short-term studies of graft load history.

2) Graft load can vary greatly during fixation if the limb is positioned manually during the procedure.

3) Graft load may be unintentionally increased if interference screws are used for fixation.

4) The ACL plays a role in controlling joint motion during the stance phase in pigs.

5) Graft pretension affects the ligamentization process. Hence, it may be more advantageous to select a pretension that better remodels the graft into a ligamentous tissue as opposed to one that best restores intact knee kinematics.

6.3 Recommendations For Future Research

6.3.1 Restoration of Knee Kinematics

The inability to restore intact knee kinematics even when using what could be considered the ideal graft is not readily explained. The only variable that might be controlled to a greater degree is that of bone plug toggle. The possibility exists that freeing the bone plug allowed a minimal amount of transverse plug movement, thus altering the forces developed in the ACL during subsequent knee motion. One way to eliminate bone plug toggle would be to design a cap that encased the plug to the level of the tibial plateau, thereby occupying the space that was created during plug formation. If a cap of this type were to be used, no room would exist for the bone plug to toggle. A limitation to this approach would be the increased friction from contact between the cap and the bone tunnel wall. A low coefficient of friction material could perhaps be used to minimize this drawback.

6.3.2 Porcine Knee Kinematics

The use of animal models to study complex situations is limited in direct application to humans by the understanding of the model. To fundamentally develop an in vivo model for ACL reconstruction, porcine knee kinematics have been compared to human knee kinematics in vitro. A description of in vivo porcine knee kinematics would be beneficial to expand knowledge of the model and to aid in the transfer of conclusions based on the model to humans.

6.3.3 Mechanical Characteristics of Patellar Tendons

Variances in the mechanical characteristics of patellar tendons from different species may offer insight to theoretical and practical considerations of tissue mechanics and warrant future exploration. For example, an examination of patellar tendon insertion site fibrocartilage may explain why the patellar tendons from some species are more susceptible to avulsion than those from other species. In another example, differences in patellar tendon ultimate properties between species may be correlated with differences in biochemical structure to possibly deduce a connection between biochemistry and mechanical strength.

6.3.4 In Vivo Graft Pretension Effects

Future in vivo work with this model should concentrate on eliminating the problems that existed with the load cell/telemetry system. First, the unpredictable changing of the transmitter settings can be eliminated by "burning" the appropriate values into the device's electronics. While this would preclude the ability to program the transmitter for future applications, the appropriate settings for the current use would be guaranteed to be stable. Second, to prevent catastrophic failure of the system in vivo, a load cell with a sturdier lead wire/transducer junction should be acquired. An ancillary benefit from doing so would be increased waterproof protection. Incorporating a new load cell may require the redesign of the connection pieces. If so, perhaps the device may be designed to encourage bone growth and viability in the tibial tunnel after an initial load monitoring period to reduce effects of necrosis during mechanical testing.

Following the aforementioned improvements, future work with the load cell/telemetry system should focus on increasing sample size for the experiment. The conclusions offered are based on experiments with a small number of animals. To increase confidence in these conclusions, more animals should be used. Additionally, other aspects should be incorporated to more fully document the experiment. For instance, joint kinematics, ground reaction forces, and velocity of the animal may be measured to better correlate activity with graft load history.

Another area of study to improve the outcome following ACL reconstruction may be biochemical or genetic in nature. By stimulating the graft biochemically or genetically, it may be possible to form a remodeled tissue with mechanical properties more similar to the intrinsic ACL, and the goals of a reconstruction may be better achieved. The load cell/telemetry system may be used during such studies to monitor and account for any effects of graft load history.