Design of an Anterior Cruciate Ligament Prevention Program for College Athletes

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***Abstract*— The anterior cruciate ligament (ACL) is located in the knee between the thigh and shin bones. When it tears, it cannot heal itself, therefore, a surgeon must surgically insert a graft into the patient's knee to replace the old torn ACL. Recovery then takes upwards of a year. For a college athlete who has a 13% chance of tearing their ACL, if they do tear it, they can lose over a quarter of their entire career. There are a couple main people who will be affected if a system can be put in place to decrease an athlete's likelihood of an ACL tear. Those people are the athlete, the surgeon, NCAA, insurance companies, as well as a few others. This brings us to our problem statement, from our research we have determined 13% of NCAA athletes participating in dynamic sports tear their ACL in non - contact injuries each year, only 33% of coaches implement a repression training, and nobody is accountable for preventing an ACLI. The need statement that will create a win - win scenario is there needs to be a precise system that quantifies the risk of an ACL tear, lowers the probability of an ACL tear resulting from non - contact athletic moves by XX%, and a way to implement and enforce the system to all athletes throughout their college career. We will achieve this win - win by developing a unified action plan for the NCAA and the insurance companies. They will develop a rule that requires colleges to do a form of analysis to determine the probability of tear, a way to mitigate it, and a way to warn if fatigue is high. The design alternatives include visual, clinical, and laboratory based analysis for the identification process. For mitigate there are braces, knee sleeves, and athletic tape. To warn the athlete about fatigue they will either use the polar heart rate monitor or smart knee brace. In the end, we hope to find the best combination of alternatives to give to the insurance company's plan of action to make the most money.**

I. Introduction

An anterior cruciate ligament injury (ACLI) occurs when an athlete is performing a specific move that changes direction quickly. The ACL is supposed to move in a hinge like manner. However, when an athlete lands incorrectly or moves in an unsafe fashion; this causes a disproportionate amount of stress on the ACL that leads to its rupture. ACLI can be broken up into two categories, rotations (non-contact) which make up 70% of ACLI and translations (contact) which make up 30%. The non-contact injuries can be broken down even further into five categories, internal/external (A 16%), adduction/abduction with rotation (A&B 37%), flexion/extension with rotation (A&C 1%), adduction/abduction alone (B 9%), and flexion/extension alone (C 37%). Due to the fluid in the knee, known as synovial fluid, which has the main purpose of absorbing shock and allowing for easy movement, the ACL cannot mend itself. The fluid prevents the two ends from meeting and forming a platelet bridge to help the healing process. This inability to heal itself causes the knee to require a graph in order to regain its entire mobility and function.

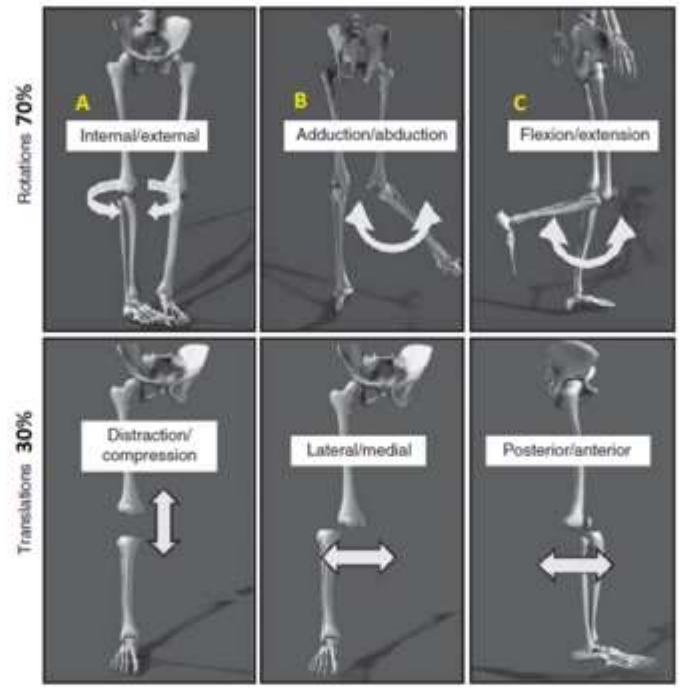


Image 1

II. Stakeholder Analysis

The primary stakeholders are the collegiate athletes (CA), coaching staff, athletic trainers, NCAA, Insurances, surgeons, and team physicians. The CA wants to increase average playing time and increase media exposure. An ACL tear may reduce their opportunity in going to the professional level. It also has a few possible physiological side effects such as fear of the sport, develop depression, and/or develop anxiety that may affect their educational performance. The CA would benefit from the ACL Repression Program because it would reduce the probability of an ACI. The coaching staff's main objective is to increase winning percentages. In order to achieve that, the coach needs to have the whole team available, ready, and their fitness level are up to the desired level. The athletic trainers are professional who are assigned to develop sport medical programs that aims to maintain or improve the athlete's' fitness level. The insurance companies pay for the ACL reconstruction surgery. Their main objective is to make profit. A repression program will be beneficial to them if it cut on the number of ACL injuries per year because it will reduces their average spending on ACL surgeries. The

NCAA regulates the rules of collegiate sports. They determine participants' eligibility of colleges and student athletes, and which division they will compete in. The NCAA are considered as a non- profit organization, in which the money flow coming in from media rights are used to benefit only NCAA participants. Surgeons perform the grafting to the CA when they tear their ACL. A repression program would negatively impact the surgeons because it would decrease the client pool for the surgeons. Team physicians have the power to determine athletic exposure eligibility for student athletes. If the student athlete was injured or at high risk levels of injury, the head coach cannot make the student athlete play, and athletic trainers are instructed by the team physician to develop a sport medical program that meets the need of the student athlete.

With the knowledge of the stakeholders it is inevitable that there will be tensions. There are two main tensions. One, a decrease in ACLI means a decrease in surgeries which means less money for the surgeons. Two, the NCAA regulates the athletic competition for the competing athletic departments from each college. To be able to pay for athletic expenses such as athletic staff salaries, athletic equipment (support gear, monitoring gear, and motion analysis tools), athletic clothing, transportation for away games, and other expenses, colleges need to fund the athletic department. Additional to these cost, the NCAA require that the athletic department also pays for insurances that covers up to $90,000 athletically related injuries paid to orthopedic surgeons and physical therapists for ACLI patients. The higher ACL injury rates, the higher the demand for them. Team physician have the authority over the head coaches and athletic trainers to determine the eligibility for athletic exposures, this relates with the goals of the college institutions. Tool manufacturers create equipment for different types of training. By implementing this system, they will have a larger pool of customers which will affect them positively.

III. NEED STATEMENT

There are a couple gaps in the existing system. One, only 33% of colleges implement injury prevention programs even though they have been shown to reduce the likelihood of an ACLI. And two, current visual analysis done by the colleges that actually implement prevention programs do not quantify ACL load, and cannot determine the internal structure during load bearing activities. This brings us to our problem statement, from our research we have determined 13% of NCAA athletes participating in dynamic sports tear their ACL in non - contact injuries each year, only 33% of coaches implement a repression training, and nobody is accountable for preventing an ACLI. The need statement that will create a win - win scenario is there needs to be a precise system that quantifies the risk of an ACL tear, lowers the probability of an ACL tear resulting from non - contact athletic moves by XX%, and a way to implement and enforce the system to all athletes throughout their college career.

IV. ALTERNATE CON-OPS

There are some factors that play a role in ACLI; the main ones are body mass, tibia length, knee valgus motion, knee flexion range, and quadriceps hamstring ratio. Body mass is the weight of the individual in kg. The higher the mass the higher the force the body has to absorb. Tibia length is the length of the shins. This relates to torque, the longer the tibia, the more force applied. The equation is Knee Abduction Moment = Body Mass * Gravity * Tan(Q)* Tibia Length. Knee valgus motion is the change in distance the knee moves in the Sagittal plane during a drop jump movement. This applies more horizontal force to the ACL. Knee flexion range of motion is the difference in flexion angle at the beginning of an athletic movement and the end. The equation is Knee Flexion Range of Motion = (1- 2)

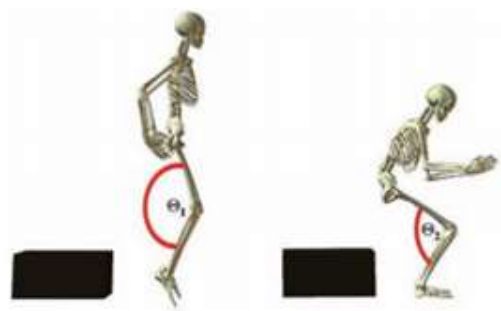


Image 2

Quadriceps Hamstring Ratio is the muscular forces acting on the knee and ACL. Contraction of the quadriceps tends to pull the tibia forward while contraction of the hamstrings tends to pull the tibia backwards. Hamstring activation tends to help stabilize the knee and support the ACL during landing and cutting movements. Quadriceps Hamstring Ratio can be written as Quadriceps Hamstring Ratio = Quadriceps Strength Hamstring Strength. The whole equation is listed below (derived from Myer et. al. study). There are three other main factors that play a role in ACLI but we have yet to determine the exact correlation. Those are fatigue level, shoe-surface interface (coefficient of friction), and hormones.

Probability (tear) = Body Mass + Quadriceps Hamstring Ratio + Knee Valgus Motion + Tibia Length – Knee Flexion Angle

In our need statement, we isolated the necessity for a method to enforce an ACLI repression system. We conducted stakeholder analysis with the George Mason University soccer team to find out if there is an enforcement system already in place. After interviewing John C. Delgado, the assistant strength and conditioning coach who runs the current repression for the female teams, we found out that there is no mandated repression program in place by the NCAA. This information combined with information from a study that states that only 33% of high school coaches implement a form of repression <Norcross 2015>, we isolated the need for a method to enforce ACLI repression programs for college athletes.

The reason we chose to focus on college athletes is because from our further research into authority of the NCAA, we found a few NCAA regulations that we could leverage to enforce a repression program.

“A member of the institution’s sports medicine staff should be empowered to have the unchallengeable authority to cancel or modify a workout for health and safety reasons, as he or she deems appropriate. A member of the institution’s sports medicine staff should be empowered and protected when reporting events thought to endanger a student athlete or conflict with the institution’s medical care and safe environments policies.”<NCAA Sports Medicine Handbook 2014>

A team physician has the authority to remove a player from a workout or competition for health and safety reasons. This shows us that there is an enforcement method that we could leverage if we could show that there are different probabilities of ACL tear based on individual metrics. Also if we could define a certain level of probability of ACL tear, say 30% based on our simulation model, we plan on defining a medical syndrome following this logic. If a player is found to be above our defined probability of tear then they would have that medical syndrome, high tear syndrome. With this defined syndrome, the NCAA could make a regulation that would enforce the team physicians to look for high tear syndrome and then remove those athletes from play or workout.

To define a medical syndrome based on probability of tear, we will need a study showing that there is a proven increased risk for some athletes to tear their ACL’s. This study is being laid out by this senior design project. Since our project is showing the capability of a repression system, the further undertaking to adapt the system will be enacted by a larger study with a good amount of funding.

This larger study will use our logic and method of analysis on a larger scale to develop the necessary identifying mechanism of ACL injuries. Also this study will fund the implementation of our system. Our system will cost $XX and therefore will need contributions from a large economical stakeholder.

From further stakeholder analysis we found that Insurance Companies are the ones that have the most economical impact on ACL injuries. They also stand to benefit by the decrease of the number of ACL injuries.

There are four main equations used to calculate this.

1. Insurance Profit = (Total Premium Intake) – (Total Cost of Implementing System) – (New Payout Cost after Implementing System)

2. Total Premium Intake = (# of Insured Athletes)*(Premium Rate of Athletes)

3. Total Cost of Implementing System = (Identify Costs) + (mitigate Costs) + Warn Costs)

4. New Payout Cost After Implementing System = (Current # of ACLI)*(1 – Change % System Reduction Requirement)

These equations show that the insurance companies stand to profit by the effectiveness of our system. Leveraging the insurance companies is key to the implementation of our system and the overall lessening of ACLI occurrences.

V. TECHNOLOGIES

We have up with three sets of design alternatives, identify mitigate, and warn. Identify and mitigate have three options and warn has two.

The design alternatives for identify include visual, clinical, and laboratory based analysis. These are three different ways to determine athletes at a high risk of an ACL tear. Visual analysis is the current as-is system for teams that do prevention programs, a physical trainer will monitor a team of athletes performing various dynamic movements, and assess the athlete’s probability of tear visually. A few advantages of this design alternative are that it provides direct observation or description of injury mechanism, has no side effects, and is comprised of primary or secondary information. The clinical analysis alternative would be similar to an athlete's’ yearly physical exam with the addition of performing a drop-jump test to view neuromuscular deficiencies. Advantages of this alternative are it evaluates the athlete’s probability of tear during times of high knee load, has an adequate specificity of 60-72%, and can be performed during the athletes’ yearly physical. During a laboratory based analysis an athlete performs dynamic movements while wearing node clusters and being recorded by multiple cameras. The resulting recordings are then used to recreate the movements in computer software, and are then analyzed. Advantages of this alternative are that it returns metrics to the athlete; it uses highly sensitive cameras during the analysis, provides the athlete with a 3D model of their body, and is able to take into account knee abduction angle and knee abduction moment.

The mitigation design alternatives provide ways an athlete may reduce the chance of tearing their ACL. DJO functional bracing provides knee support to counteract excess horizontal force on the knee. This alternative reduces an athlete's’ ACL strain by 50%. The advantages of the DJO functional bracing are it can control rotation instability, reduces tibia shear force applied on the tibia by the quadriceps, and increased knee flexion angle by seven degrees. Knee sleeves are another alternative for the mitigation system. They are similar to the DJO functional bracing in terms of providing the knee system support during times of heavy load. Some advantages are they relieve pressure on the knee, improve coordination, and are significantly less costly than the DJO functional bracing. KT tape also provides the knee system with support during dynamic movements to reduce the likelihood of suffering an

ACL tear. Advantages of this alternative are that it supplies support to the joint by restricting movement and is the cheapest alternative for the mitigation system.

The warn design alternatives provide the coaches and athletes a way to monitor the fatigue level of an athlete. The Polar heart rate monitor tracks the athlete's' level of fatigue through heart rate readings. Athletes' could wear this alternative during games underneath their jersey, and the heart rate of the athletes' could be tracked by the coach through the accompanying software. Increased fatigue level in athletes' can lead to poor neuromuscular form during dynamic movements, which can make athletes have a higher probability of incurring an ACLI. Advantages of this alternative are that it can used by coaches during practice as well as official games, it does not have any side effects, and has a battery life that can be used for twenty-four hours a day for two weeks. Smart knee by Bendlabs is a knee brace with sensors that is able to track complex knee motion. This alternative uses silicon sensors to measure knee system angles, estimated amount of knee load, and an estimated q-angle during dynamic movements. The data gathered by the sensors are sent via Bluetooth to a device with the accompanying software to be analyzed and displayed as quantitative metrics. Advantages of the Smart Knee are that it provides metrics in real time, it is simple to use and read data from, and it is safe to use with no side effects.

VI. METHOD OF ANALYSIS

The objective of our simulation is to simulate our system concept using inputs from a kinematic model and different values for our design alternatives. The model that we will be developing over the winter break has a specific set of requirements. Requirement one and its sub-requirements deal with the different types of inputs used to calculate out the probability of tear. They are all body metrics and error rates associated with each type of identify, mitigate, and warn option. Requirement two describes the output. It is a probability of tear with a specific confidence interval. Requirement three and four state that there will be personas and the probabilities will be sourced. The personas will have values for tibia length, mass, quadriceps hamstring ratio, knee flexion angle, knee valgus motion, identification error rate, mitigation error rate, and warn error rate. Each persona will have an associated probability of tear. Requirements five and six describe how the simulation will run using a Monte Carlo simulation.

The picture below is a visual representation of what our simulation will look like. The green boxes are the inputs that we know how they relate to ACL tears. The red boxes are inputs that we know exist but are not sure how they relate to ACL tears yet. The black box represents the model. This will be the error percentages associated with each sub system. The output in blue is the probability of tear with the associated confidence interval.

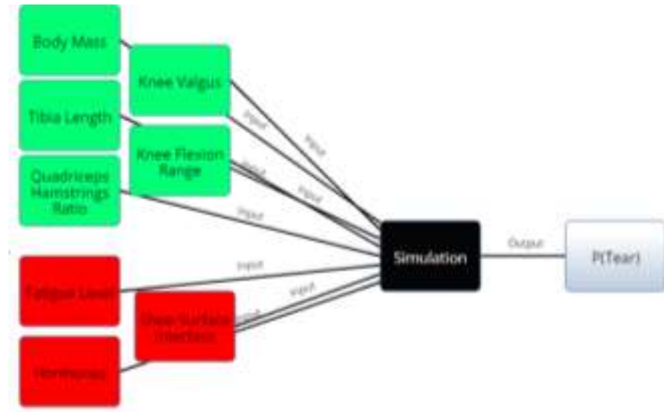
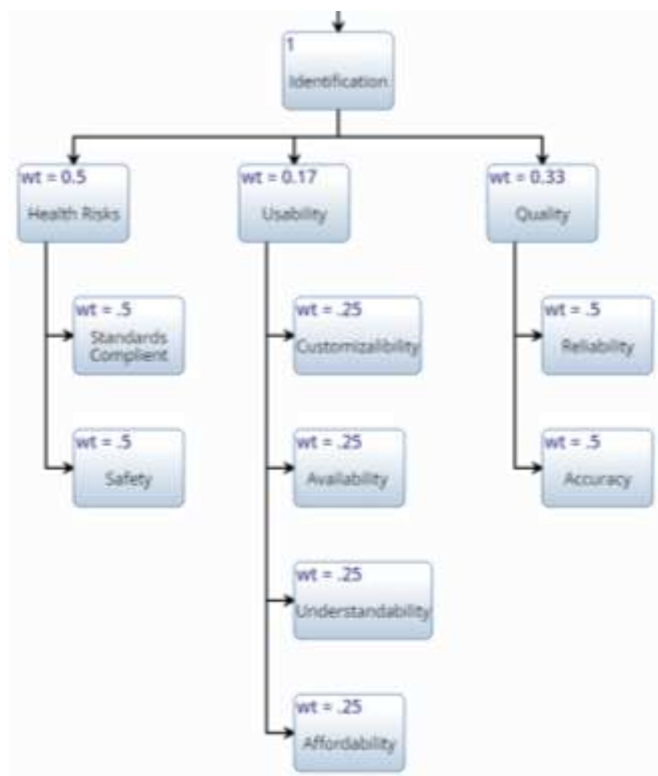


Image 3

Our value hierarchy was broken into three sections identification, mitigation, and warning. For identification there are three categories, health risks, usability, and quality. Mitigation has two categories, quality and compliability. And warn has three categories, health risks, quality and usability.

After talking with the stakeholders we determined these weights. The main stakeholder we talked with was the GMU athletic trainer. The weights are in the upper left corner.



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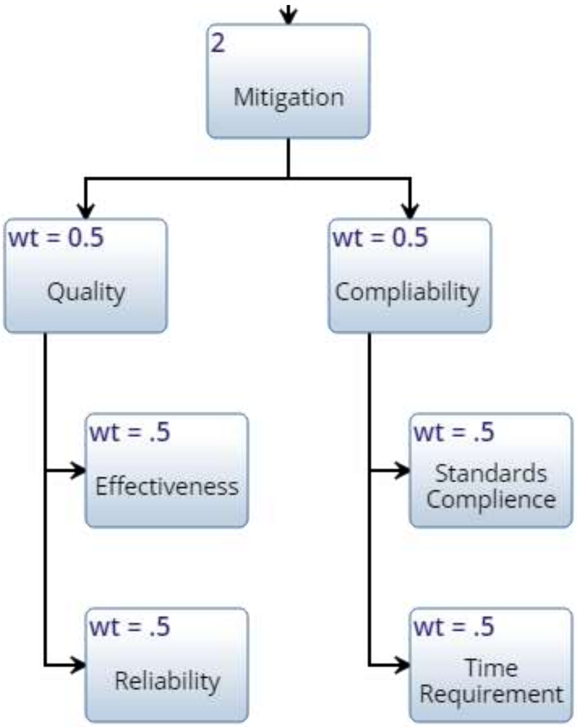

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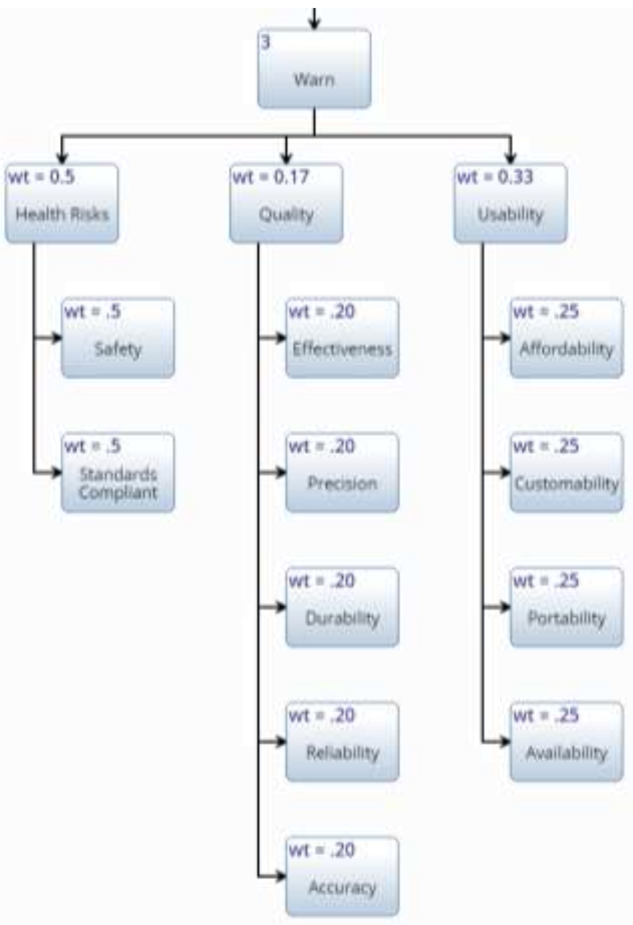

Image 6

The design of experiment will consist of a table of personas being tested for their probability of tear. From there the persona will be given a mitigation option and a warn option each with a likelihood of working. The persona table will look like the below table.

	Tibia (cm)	Mass (kg)	Ratio (%)	Flexion (deg)	Valgus (cm)	Output
1	26	70	59	4	12	0.76
2	50	55	75	22	7	0.45
3	48	60	55	45	11	0.66
4	35	100	60	80	5	0.88
…	…	…	…	…	…	…
5	41	40	66	97	3	0.48

Table 1

V. RESULTS

The results for our simulation will show the identification rate, mitigation rate, and successful warn rate for each combination of the design alternatives. After we determine our results, we will create a utility versus cost analysis. This will show us the combination of design alternatives that give us the most for the specific cost we are willing to settle for. The graph will show the best combinations of design alternatives multiplied the weights in our value hierarchy against the total cost of those combinations of design alternatives. This will also show which alternatives meet the requirements and which should not even be considered. A Utility vs Cost analysis is integral to leveraging the Insurance companies and therefore the implementation of our system. A key factor will be how the insurances profit will result from the effectiveness of our system. After we analysis our results from our simulation, we will run a sensitivity analysis. From here we may change the weights of the -ilities. This may open up some other options that may have been just short of the cut off.

VI. CONCLUSIONS

Once finished with the simulation results, utility versus cost analysis, and sensitivity analysis we will be able to give recommendations and come to conclusions about our model. This will give us our win - win scenario that will give us a precise system that quantifies the risk of an ACL tear, lowers the probability of an ACL tear resulting from non - contact athletic moves by XX%, and a way to implement and enforce the system to all athletes throughout their college career.

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