DESIGN OF AN ANTERIOR CRUCIATE LIGAMENT INJURY REPRESSION SYSTEM

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SENIOR DESIGN SYST 490 - 001

It is said that 10,000 of practice hours creates expertise.

For an athlete, one wrong step can take all that away.
1. CONTEXT
2. CONOPS
3. ANALYSIS METHODOLOGY
4. PROJECT PLAN AND BUDGET
1. CONTEXT

- Definitions
- The Knee System
- Why are ACLI More Serious than Other Ligament Injuries?
- Average ACLI Incident
- Defining Project Scope
- Project Scope
- Knee Biomechanics
- Risk Factors
- Structural
- Neuromuscular
- Muscular
- As-Is
- Gap Analysis
- Stakeholder Analysis
- Problem & Need Statements
DEFINITIONS

• ACL – Anterior Cruciate Ligament
• ACLI – Anterior Cruciate Ligament Injury
• Sub-Systems of ACLI Handling
  – Repression – the attempted prevention of an ACLI
  – Reconstruction – the surgical process to repair an ACLI
  – Rehabilitation – the process of returning to previous level of athletic effort
• Knee Dynamics
  – Valgus – knees coming together during athletic movement
  – Quad Dominance – using quadriceps to absorb all the shock
  – Q- angle – the angle between hip and the knee
• Dynamic Sports - Competitive physical activity characterized by constant change.
THE “KNEE SYSTEM”

1. Femur
2. Knee Cap
3. Shin
4. Fibula
5. Quadriceps Tendon
6. Patellar Tendon
7. Hamstring Tendons
8. Quadriceps
9. Hamstring
10. Calf
11. Meniscus
12. PCL
13. MCL
14. LCL
15. ACL

OhioDance <2012>  Wikipedia <2015>
WHY ARE ACLI MORE SERIOUS THAN OTHER LIGAMENT INJURIES?

• The Synovial Fluid
  – Non-Newtonian Fluid that reduces friction between the cartilage
• Effects the ACL healing process
  – Prevents blood from clotting on the torn ACL
  – Blood clotting acts like a reconstructive scaffold that facilitates scar tissue creation and healing.
• HyrdaRub <2006>

  It won't heal on its own.

Dr. David Geier <2014>
## AVERAGE ACLI INCIDENT BY SPORT AND GENDER FOR AN NCAA ATHLETE

<table>
<thead>
<tr>
<th>Sport</th>
<th>Female</th>
<th>Percentage</th>
<th>Male</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basketball</td>
<td>15,381</td>
<td>29%</td>
<td>16,911</td>
<td>8%</td>
</tr>
<tr>
<td>Soccer</td>
<td>23,357</td>
<td>32%</td>
<td>21,601</td>
<td>12%</td>
</tr>
<tr>
<td>LAX</td>
<td>7,219</td>
<td>18%</td>
<td>9,266</td>
<td>17%</td>
</tr>
<tr>
<td>Football</td>
<td>0</td>
<td>0%</td>
<td>64,879</td>
<td>2%</td>
</tr>
<tr>
<td>Rugby</td>
<td>184</td>
<td>36%</td>
<td>63</td>
<td>18%</td>
</tr>
<tr>
<td>Average</td>
<td>28.75%</td>
<td></td>
<td>11.40%</td>
<td></td>
</tr>
</tbody>
</table>

Females have a 16 degree Q-Angle on average compared to a Male's 12 degree

![Return to Sports Diagram]

Lee DY <2007>
DECIDING ON PROJECT SCOPE

Failure Rate = Failed Outputs/ Inputs
ESTABLISHING OUR PROJECT SCOPE

Reasons to narrow scope to Repression:
- No unifying stakeholders governing all three processes.
- Phase 1 processes hold most weight.
- Our simulation shows that Repression contributes the most error to our system and therefore the most opportunity.
- Repression has the most developed CONOPS and Design Alternatives.
MECHANISM OF ACL INJURY

<table>
<thead>
<tr>
<th>Of Non-Contact Injuries</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A&amp;B</th>
<th>A&amp;C</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>16%</td>
<td>9%</td>
<td>37%</td>
<td>37%</td>
<td>1%</td>
</tr>
</tbody>
</table>

- 70% of injuries are non-contact
- 30% are contact
- Different knee joint rotations loads the ACL at different rates.
- Maximum shear force failure of an ACL = 2150 ± 157N

Yohei Shimokochi <2008>
Carmen E. Quatman <2010>
RISK FACTORS ARE SIMULATION INPUTS

- **Structural**
  - Body Mass
  - Tibia Length

- **Neuromuscular Control**
  - Knee Valgus
  - Knee Flexion Range

- **Muscular**
  - Quadriceps Hamstring Ratio

- **Other**
  - Fatigue Level
  - Shoe-Surface interface
  - Intercondylar Notch Width
  - Hormones

ACL fails if: ACL load >= Max Stress to Failure
The higher the **BODY MASS** the higher the force the body has to absorb to be erect.

\[ \text{Knee Abduction Moment} = \text{Body Mass} \times \text{Gravity} \times (\tan(\theta)) \times \text{Tibia Length} \]
Knee Valgus Motion

Knee valgus motion is the change in distance the knee moves in the Sagittal plane during a drop jump movement.

Knee Flexion Range Of Motion

\[ \text{Knee Flexion Range of Motion} = (\theta_1 - \theta_2) \]

Gregory D. Myer <2010>
The Quadriceps and Hamstrings have a complex relationship in regards to inputs to ACL Load.
CURRENT REPRESSSION SYSTEM: TEAM TRAINING

- Prevent Injury and Enhance Performance Program (PEP)
  - Running
  - Flexibility
  - Strength
  - Plyometric
  - Agility
- Knee Injury Prevention Program (KIPP)
  - Plyometric
  - Strength
  - Agility
- Other
  - Sportsmetrics
  - Herman
  - Lephart
  - Derived Prevention Programs

- 62% Reduction in P( tear)
  - 52% in Females
  - 85% in Males

Noyes, Westin<2013>

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Duration</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Texas</td>
<td>$300</td>
<td>6 weeks</td>
<td>3x per week</td>
</tr>
<tr>
<td>Pediatric Orthopedics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimate Per School Year</td>
<td>$1,800</td>
<td>36 weeks</td>
<td>3x per week</td>
</tr>
</tbody>
</table>
Only 33% of colleges implement injury prevention programs

MARC F. NORCROSS <2015>

Does not quantify ACL load, and cannot determine the internal structure during load bearing activities
STAKEHOLDERS

• Athlete
• Coaching Staff
• Trainers
• Team Physician
• Insurances
• NCAA
• Teammates
• Family of Athlete

• Sponsors
  – College Institutions
  – Athletic Clothing Brands
• Orthopedic Surgeons
• Tool Manufacturers
  – Support Gear
  – Monitoring Tools
  – Motion Analysis
PROBLEM STATEMENT

13% OF NCAA ATHLETES PARTICIPATING IN DYNAMIC SPORTS TEAR THEIR ACL IN A NON-CONTACT INJURIES EACH YEAR AND ONLY 33% OF COACHES IMPLEMENT REPRESSION TRAINING AND NOBODY IS ACCOUNTABLE.
NEED STATEMENT

THERE NEEDS TO BE A PRECISE SYSTEM THAT QUANTIFIES THE RISK OF A TEAR, LOWERS THE PROBABILITY OF TEAR RESULTING FROM NON-CONTACT ATHLETIC MOVES BY XX%, AND WAY TO IMPLEMENT AND ENFORCE THE SYSTEM TO ALL ATHLETES THROUGHOUT THEIR COLLEGE CAREER.
2. CONCEPT OF OPERATIONS

- Stakeholder Unified Action Plan
- NCAA Influence
- Stakeholder Tensions
- Why this strategy is possible
- Leveraging Insurance Companies
- Mission Requirements
- CONOPS
- Functional Requirements
- Design Alternatives
- Design Requirements
- Evaluation of Design Alternative (Identify)
- Evaluation of Design Alternative (Mitigation)
- Evaluation of Design Alternative (Warn)
An insurance company stands to benefit from a system that lowers the occurrence of ACLI. The system will need to be funded by the NCAA and another sponsor. The National Collegiate Athletic Association is a membership-driven organization dedicated to safeguarding the wellbeing of student athletes. Has the power to create and enforce regulations. The NCAA gives the Physicians power to prevent Athletes from play based on Medical reasons. Facilitates Mitigation. Has a probability of tearing their ACL.
A NCAA REGULATION CAN LOWER NUMBER OF TEARS

START
Define athletes with a High Probability of tear as having High Tear Syndrom

NCAA Makes Regulation that says athletes with High Tear Syndrom can't play

Team Physicians are held accountable By regulations

Coaches, Trainers and Players are held accountable by physicians.

Athletes with High Tear Syndrom are seated, lowering overall tear rates and satisfying our requirements.

END
STAKEHOLDER TENSIONS (TO-BE)
WHY THIS STRATEGY IS POSSIBLE

The NCAA teamed up with the DOD to fund a $30 million dollar concussion handling project. NCAA.org <2015>
LEVERAGING INSURANCE COMPANIES

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) +
   (Mitigation Costs) +
   (Warn Costs)

4) New Payout Cost after Implementing System = (Current # of ACLI’s) *
   (1 – Δ%System Reduction Requirement)
# MISSION REQUIREMENTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR.1</td>
<td>The system shall reduce the probability of ACLI in collegiate athletes by XX%.</td>
</tr>
<tr>
<td>MR.2</td>
<td>The system shall work with individual athlete’s ranges of motion specific to the sport.</td>
</tr>
<tr>
<td>MR.3</td>
<td>The system shall cost no more than 80% the profit of the insurance company.</td>
</tr>
<tr>
<td>MR.4</td>
<td>The system shall cover an athlete through their entire NCAA career.</td>
</tr>
<tr>
<td>MR.5</td>
<td>The system shall not detract from a coach’s coaching time.</td>
</tr>
<tr>
<td>MR.6</td>
<td>The system shall be maintained throughout an athlete's NCAA career.</td>
</tr>
</tbody>
</table>
PROPOSED SYSTEM
## FUNCTIONAL REQUIREMENTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR.1.1</td>
<td>The system shall decrease ACL strain caused by knee valgus angle by XX%</td>
</tr>
<tr>
<td>FR.1.2</td>
<td>The system shall decrease strain caused by mass by XX%</td>
</tr>
<tr>
<td>FR.1.3</td>
<td>The system shall decrease strain caused by quadriceps/hamstring ratio by XX%.</td>
</tr>
<tr>
<td>FR.1.4</td>
<td>The system shall decrease strain caused by knee flexion angle by XX%.</td>
</tr>
<tr>
<td>FR.2.1</td>
<td>The system shall identify an athlete's probability of tear with XX% confidence.</td>
</tr>
<tr>
<td>FR.2.2</td>
<td>The system shall use team training, private training, and/or supports to mitigate an athlete’s probability of tear by XX%.</td>
</tr>
<tr>
<td>FR.2.3</td>
<td>The system shall use warning tools monitor athlete's fatigue level with XX% confidence.</td>
</tr>
<tr>
<td>FR.4.1</td>
<td>The system shall start when an athlete starts a college sport.</td>
</tr>
<tr>
<td>FR.4.2</td>
<td>The system shall end when the athlete chooses to leave the sport.</td>
</tr>
<tr>
<td>FR.4.3</td>
<td>The system shall end when the athlete becomes ineligible to compete in the sport.</td>
</tr>
<tr>
<td>FR.6.1</td>
<td>The system shall receive updates within 30 days of a new and confirmed scientific study suggesting change.</td>
</tr>
</tbody>
</table>
DESIGN ALTERNATIVE
## DESIGN REQUIREMENTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR.1</td>
<td>The system shall have non-dangerous, NCAA approved materials for equipment.</td>
</tr>
<tr>
<td>DR.2</td>
<td>The system shall take no longer than XX minutes to identify through each iteration.</td>
</tr>
<tr>
<td>DR.3</td>
<td>The system shall take no longer than XX minutes per week to mitigate.</td>
</tr>
<tr>
<td>DR.4</td>
<td>The system shall be able to monitor for a minimum of XX minutes per day.</td>
</tr>
<tr>
<td>DR.5</td>
<td>The system shall identify high risk athletes every 8 weeks.</td>
</tr>
<tr>
<td>DR.6</td>
<td>The system shall suggest a way to mitigate p(tear) based on how it was identified.</td>
</tr>
<tr>
<td>DR.7</td>
<td>The system shall suggest a way to control p(tear) based on how it was failed to be mitigated.</td>
</tr>
<tr>
<td>DR.8</td>
<td>The system shall not decrease an athlete’s athletic ability.</td>
</tr>
<tr>
<td>DR.9</td>
<td>The system shall decrease an athlete’s p(tear) by identifying, mitigating, and controlling.</td>
</tr>
</tbody>
</table>
## EVALUATION OF DESIGN ALTERNATIVE: IDENTIFY (1)

<table>
<thead>
<tr>
<th>Design Alternative</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Additional Cost</th>
</tr>
</thead>
</table>
| **Visual Analysis** | • Direct observation or description of injury mechanism  
• Safe, and does not have side effects  
• First or second hand information | • Cannot determine internal structure stresses/strains  
• Has to only focus on one at a time  
• Video needs to be reviewed  
• Error prone | $(# \text{ of extra hours } \times \text{ physical trainer payrate})$ |
| **Clinical Analysis** | • Able to view neuromuscular deficiencies  
• Can be done during an athlete’s yearly physical  
• Evaluates p(ear) during dynamic movements  
• Adequate specificity 60-72% | • Cannot determine internal structure stresses/strains  
• Need trained team physicians  
• Risk of injury during drop-jump test  
• Low sensitivity, ranging from 67-87% | $(# \text{ of extra hours } \times \text{ doctor payrate})$ |
| **Laboratory Based Analysis** | • Sensitive camera 5,000 frames  
• 6 cameras to do 3D analysis  
• Build a computer model from data gathered from node clusters placed on athlete  
• Able to take into account knee abduction angle and knee abduction moment | • Need supervision  
• Takes 1 hour to calibrate  
• $9,600+$ | $100 \text{ per person}$ |
## EVALUATION OF DESIGN ALTERNATIVE: MITIGATE (2)

<table>
<thead>
<tr>
<th>Design Alternatives</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Additional Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJO Functional Bracing</td>
<td>• Reduces ACL strain up 50%</td>
<td>• More effective in rehab</td>
<td>$899.99 per person</td>
</tr>
<tr>
<td></td>
<td>• Control rotation instability</td>
<td>• Some braces have metal or hard plastic, dangerous</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reduces tibial shear force applied on the tibia by the quads</td>
<td>• Expensive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increases knee flexion angle by 7 deg</td>
<td>• May influence performance</td>
<td></td>
</tr>
<tr>
<td>Knee Sleeves</td>
<td>• Relieves pressure</td>
<td>• No data that it reduces ACL strain</td>
<td>$39.85 per person</td>
</tr>
<tr>
<td></td>
<td>• Improves coordination</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Offer knee stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cheaper than knee brace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT Tape</td>
<td>• Restrict movement and supply support to the joint</td>
<td>• Knee position brace - new technology</td>
<td>$12.99 per person</td>
</tr>
<tr>
<td></td>
<td>• Cheapest alternative</td>
<td>• Could do nothing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Might weaken the knee</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Uncertainty</td>
<td></td>
</tr>
</tbody>
</table>
# EVALUATION OF DESIGN ALTERNATIVE: WARN (3)

<table>
<thead>
<tr>
<th>Design Alternative</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Additional Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Heart Rate Monitor</td>
<td>• Waterproof&lt;br&gt;• Portable, gives feedback to coach if the athlete&lt;br&gt;• Safe, and does not have side effects&lt;br&gt;• Can be used 24/7 for 2 weeks before recharging&lt;br&gt;• Measures athletes’ fatigue level</td>
<td>-Only monitor fatigue level/heart rate or knee position&lt;br&gt;-Can be uncomfortable</td>
<td>$15660 per team</td>
</tr>
<tr>
<td>Polar Electro &lt;2015&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart Knee</td>
<td>• Simple to use and read data from&lt;br&gt;• Portable, gives feedback to coach if the athlete&lt;br&gt;• Safe, and does not have side effects</td>
<td>• More effective in rehab&lt;br&gt;• Some braces have metal or hard plastic, dangerous</td>
<td>TBD</td>
</tr>
<tr>
<td>Bendlabs &lt;2015&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. ANALYSIS METHODOLOGY

- Simulation Objectives
- Simulation Requirement
- Simulation
- Design of Experiment
- Value Hierarchy
- Utility Vs Cost
The objective of our simulation is to simulate our system concept using inputs from a kinematic model and different values for our design alternatives.

Since our systems function is to lower the overall probability of tear for a population, the outputs will be probabilities of tear.
<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR.1</td>
<td>The simulation shall have human metrics for inputs.</td>
</tr>
<tr>
<td>SR.1.1</td>
<td>The simulation shall have mass for an input.</td>
</tr>
<tr>
<td>SR.1.2</td>
<td>The simulation shall have quadriceps/hamstring ratio for an input.</td>
</tr>
<tr>
<td>SR.1.3</td>
<td>The simulation shall have knee flexion angle for an input.</td>
</tr>
<tr>
<td>SR.1.4</td>
<td>The simulation shall have tibial length for an input.</td>
</tr>
<tr>
<td>SR.1.5</td>
<td>The simulation shall have knee valgus motion for an input.</td>
</tr>
<tr>
<td>SR.1.6</td>
<td>The simulation shall have an identify method error rate for an input.</td>
</tr>
<tr>
<td>SR.1.7</td>
<td>The simulation shall have a mitigation option error rate for an input.</td>
</tr>
<tr>
<td>SR.1.8</td>
<td>The simulation shall have a warning tool error rate for an input.</td>
</tr>
<tr>
<td>SR.2</td>
<td>The simulation shall have probability of tear for an output with a specific confidence interval.</td>
</tr>
<tr>
<td>SR.3</td>
<td>The simulation shall model an individual persona.</td>
</tr>
<tr>
<td>SR.4</td>
<td>The simulation probabilities shall be sourced.</td>
</tr>
<tr>
<td>SR.5</td>
<td>The simulation shall simulation 100 different athlete combination.</td>
</tr>
<tr>
<td>SR.6</td>
<td>The simulation shall run each athletic persona 100 times to model a monte carlo simulation.</td>
</tr>
</tbody>
</table>
SIMULATION

GREEN: inputs that we have figured out how they work in the equation

RED: inputs that we have not figured out how they work in the equation

\[
P(\text{tear}) = -0.731857 - 0.00221432 \text{ flexion} + 0.0030274 \text{ mass} + 0.0516676 \text{ ratio} + 0.0322922 \text{ tibia length} + 0.0357644 \text{ valgus}
\]

Came from a regression model we linearized that came from a validated study using kinematics measuring devices

Meyer et.al <2010>
### DESIGN OF EXPERIMENT TO ACHIEVE ACHIEVE EFFECTIVENESS

<table>
<thead>
<tr>
<th>Persona</th>
<th>Tibia Length (cm)</th>
<th>Mass (kgs)</th>
<th>Quad Ham Ratio (%)</th>
<th>Knee Flexion Angle (deg)</th>
<th>Knee Valgus Motion (cm)</th>
<th>Identify Error Rate (%)</th>
<th>Mitigation Error Rate (%)</th>
<th>Warn Error Rate (%)</th>
<th>P(Tear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>70</td>
<td>59</td>
<td>4</td>
<td>12</td>
<td>20</td>
<td>10</td>
<td>2</td>
<td>0.76</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>55</td>
<td>75</td>
<td>22</td>
<td>7</td>
<td>25</td>
<td>13</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>60</td>
<td>55</td>
<td>45</td>
<td>11</td>
<td>5</td>
<td>12</td>
<td>3</td>
<td>0.66</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>100</td>
<td>60</td>
<td>80</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>0.88</td>
</tr>
<tr>
<td>...</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>100</td>
<td>41</td>
<td>40</td>
<td>66</td>
<td>97</td>
<td>3</td>
<td>15</td>
<td>7</td>
<td>4</td>
<td>0.48</td>
</tr>
</tbody>
</table>
VALUE HIERARCHY
A Utility vs Cost analysis is integral to leveraging the Insurance companies and therefore the implementation of our system.

A 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.

A key factor will be how the insurances profit will result from the effectiveness of our system.
4. PROJECT PLAN AND BUDGET

- What We Have Done and Where We Want to Go
- Gantt Chart
- RACI and Budget
- EV
- CPI/SPI
- Project Risks
- Risk Matrix
### Accomplishments

<table>
<thead>
<tr>
<th>Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amassed an understanding of interrelated contributing factors to probability of tear.</td>
</tr>
<tr>
<td>Proved through a simulation that Repression contributes the most error to the system and therefore the most opportunity for improvement.</td>
</tr>
<tr>
<td>Conducted key stakeholder interviews to define the current process and to define needs and requirements.</td>
</tr>
<tr>
<td>Conducted research into design alternatives including visits to: Walter Reed Hospital, Freedom Center GaitLab and the Proactive Physical Therapy and Wellness.</td>
</tr>
<tr>
<td>Developed Win-Win stakeholder Scenario that supports the facilitation of our project.</td>
</tr>
</tbody>
</table>

### Goals

<table>
<thead>
<tr>
<th>Goals</th>
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<tbody>
<tr>
<td>Work with the kinematic model to optimize our simulation.</td>
</tr>
<tr>
<td>Create a sound project plan for the second semester using the experience we have learned.</td>
</tr>
<tr>
<td>Contact Insurance companies and the NCAA to get our business plan underway.</td>
</tr>
<tr>
<td>Using our Utility vs Cost analysis, define the most cost effective system that we can offer to our facilitating stakeholders.</td>
</tr>
<tr>
<td>Research the need and develop requirements for a portable GAIT Measurement tool (GMT copyright Amr)</td>
</tr>
<tr>
<td>Develop relationship between Brain and Neuromuscular Inputs to optimize system</td>
</tr>
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</table>
## GANTT CHART TO THE END OF THE SEMESTER

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Documentation</td>
<td>181 days</td>
<td>Wed 11/11/15</td>
<td>Mon 5/9/16</td>
</tr>
<tr>
<td>Presentations</td>
<td>12 days</td>
<td>Wed 11/18/15</td>
<td>Sun 11/29/15</td>
</tr>
<tr>
<td>Poster</td>
<td>10 days</td>
<td>Mon 11/30/15</td>
<td>Wed 12/9/15</td>
</tr>
<tr>
<td>IEEE</td>
<td>14 days</td>
<td>Fri 11/20/15</td>
<td>Thu 12/3/15</td>
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<tr>
<td>Report</td>
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<td>Wed 12/9/15</td>
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## BUDGET AND RACI MATRIX

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>R</td>
<td>Responsible</td>
</tr>
<tr>
<td>A</td>
<td>Accountable</td>
</tr>
<tr>
<td>C</td>
<td>Consulted</td>
</tr>
<tr>
<td>I</td>
<td>Informed</td>
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<table>
<thead>
<tr>
<th>Amr</th>
<th>Andrew</th>
<th>Maribeth</th>
<th>Sam</th>
<th>Amr</th>
<th>Andrew</th>
<th>Maribeth</th>
<th>Sam</th>
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<tbody>
<tr>
<td>$60</td>
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<table>
<thead>
<tr>
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<tr>
<td>168 days</td>
<td>$174,837</td>
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<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Amr</th>
<th>Andrew</th>
<th>Maribeth</th>
<th>Sam</th>
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<tbody>
<tr>
<td>Analysis</td>
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<td>R</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>CONOPS</td>
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<td>C</td>
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<tr>
<td>Documentation</td>
<td>C</td>
<td>C</td>
<td>I</td>
<td>A</td>
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<td>Modeling</td>
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<td>A</td>
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<td>Project Briefing</td>
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<td>R</td>
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<td>Time Sheets</td>
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<td>Weekly Accomplishment Summaries</td>
<td>R</td>
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<td>A</td>
<td>R</td>
</tr>
</tbody>
</table>
CPI/SPI

- Our Cost Performance Index has been from 1 to 1.4. This means that we are not wasting money.
- Both CPI and SPI are close to 1
- We have had a “need already satisfied by new concurrent study” effect that caused early disparity in production.
- Modeling this better in our schedule could increase our SPI score and give a better approximation early on.
- Lesson learned is to not underestimate research time needed and to model research as ongoing in original project plan.
EARNED VALUE

- We are on target with earned value analysis
- We are within our range of acceptable costs and values
- The difference between Earned Value and acceptable planned value is miniscule.
- The difference between Actual Cost and Acceptable planned value is miniscule
- This means that we are safely within our project budget and production.
## PROJECT RISK MITIGATION STRATEGIES

<table>
<thead>
<tr>
<th>Number</th>
<th>Risk names</th>
<th>Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Insurance Companies dont buy in.</td>
<td>Find another financially strong stakeholder to facilitate study with NCAA.</td>
</tr>
<tr>
<td>2.</td>
<td>Model does not solve the problem.</td>
<td>Periodic verification testing.</td>
</tr>
<tr>
<td>3.</td>
<td>Model code is inaccurate.</td>
<td>Periodic validation testing.</td>
</tr>
<tr>
<td>4</td>
<td>Model are not developed on time</td>
<td>Meet milestones.</td>
</tr>
</tbody>
</table>
## RISK MATRIX

<table>
<thead>
<tr>
<th>Probability</th>
<th>Negligible</th>
<th>Minor</th>
<th>Moderate</th>
<th>Serious</th>
<th>Critical</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>Model late</td>
<td>Code inaccurate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium High</td>
<td></td>
<td></td>
<td></td>
<td>Insurance Don't</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>Model not solve</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions?
SUPPORTING SLIDES
QUANTIFYING ACL LOADS

Probability of an ACLI = F(Quad Dominance, Q-Angle, Hormones)

Maximum stress to failure of an ACL = 2150 ± 157N

r = radius
beta = atan2(r32, (r12^2 + r22^2)^(1/2))
alpha = atan2(-r12/cosbeta, r22/cosbeta)
gamma = atan2(-r31/cosbeta, r33/cosbeta)

Wheeless’ Textbook of Orthopaedics <2013>

Scott G. Mclean <2004>
EQUATIONS FOR FORCE INPUTS OF Q-ANGLE AND QUAD DOMINANCE

• Horizontal force to the knee system is a function of Q-Angle.

\[ \text{Horizontal force} = wt \times \tan \theta_q \]

• Quad Dominance is the tendency of absorbing the normal force from the earth with knee flexion angles in the 0 to 60 degree range.
• Quad dominance can be represented in a model of Tibial Shear Force.

\[
TSF = m_z [a_{sx} \cos \theta_s - (a_{sy} + g) \sin \theta_s] + m_f [a_{fx} \cos \theta_s \cos \theta_s - (a_{fy} + g) \sin \theta_s] \\
- R_x \cos \theta_s + R_y \sin \theta_s - \sum F_{\text{Calf}}^s - \sum F_{\text{Quad}}^s - \sum F_{\text{Ham}}^s
\]

• This equation can also be expressed as.

\[ TSF = f(\text{Neuromuscular Form, Skeleton Mass, Muscle Strength}) \]

Or

\[ TSF = \text{Tibial Shear Force} \approx \text{ACL Strain} \]
NEUROMUSCULAR

• Tibial Shear Force (TSF) is the force of the tibia sliding under the knee.

• The ACL’s main purpose is to provide a counterforce to this.

• The effect of Quad Dominance has an effect on the body’s distribution of force.

• Neuromuscular Form
  – Knee Flexion Angle
  – Valgus Knee Angle

• Muscular
  – Quad/Ham Ratio

\[ TSF = \text{Tibial Shear Force} \approx \text{ACL Strain} \]

Mark Rippetoe <2015>
Cameron <2013>
STRUCTURAL: Q-ANGLE

- Horizontal force translates directly to tension force on the MCL.

- MCL protects an ACL from horizontal shear force which means a torn ACL from abduction results from MCL tear.

- James Monk <2015>

- For a 170 lb Humanoid, a degree of Q equates to an additional approximated 3 lbs of horizontal force to the knee system.

Mark Rippetoe <2015>
## GAP ANALYSIS

<table>
<thead>
<tr>
<th>Function</th>
<th>Current</th>
<th>Future</th>
<th>Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Repression</strong></td>
<td>33% of colleges do subjective repression based on coaches experience.</td>
<td>All Colleges do a proven effective repression system.</td>
<td>An enforcing entity to implement a proven repression system based on research and statistics.</td>
</tr>
<tr>
<td><strong>Identify</strong></td>
<td>Coaches do visual analysis which is imprecise because they can't see the skeleton. Bad form is subjective to the coaches experience. There is no database to track athletes needs.</td>
<td>Athletes probability of tear is determined with precise measurements and a database tracks athletes needs.</td>
<td>There needs to be a model that determines probability of tear using precise measurements. A tool that facilitates precise measurements. A computer interface to a database.</td>
</tr>
<tr>
<td><strong>Mitigation</strong></td>
<td>Coaches run exercises based on their experience.</td>
<td>A mitigation program that focuses on individual needs.</td>
<td>A method to determine Individual needs.</td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td>Up to athlete if they use supports or not. There is no data to show link to tear</td>
<td>Supports will be prescribed to athletes who need them. There will be data supporting this need to prescribe.</td>
<td>Statistics supporting that supports lower the probability of tear. A method to prescribe.</td>
</tr>
<tr>
<td><strong>Warn during play</strong></td>
<td>No data to support probability of tear to fatigue.</td>
<td>There will be statistics to show that probability of tear is a function of fatigue. The warn system will be implemented.</td>
<td>A study or model showing that probability of tear is a function of fatigue. The way to implement the warn system.</td>
</tr>
</tbody>
</table>
RISK FACTORS EFFECT ON ACL STRAIN

\[ TSF = \text{Tibial Shear Force} \approx ACL \text{ Strain} \]

\[ TSF = m_s [a_{sx} \cos \theta_s - (a_{sy} + g) \sin \theta_s] + m_f [a_{fcoxθₘ} \cos \theta_s - (a_{fy} + g) \sin \theta_s] - R_x \cos \theta_s + R_y \sin \theta_s - \sum F_{\text{calf}} - \sum F_{\text{quad}} - \sum F_{\text{ram}} \]

\[ TSF = f(\text{Neuromuscular Form, Skeleton Mass, Muscle Strength}) \]
EXTERNAL

- Shoes-Surface Interaction
  - Increasing COF of shoe surface interaction results in decreasing knee flexion angle and increasing knee loading resulting in an increased risk of ACL injury

- Shoes
  - models with longer and narrower cleats increase COF

- Surface
  - Outdoor: grass (low COF) vs Artificial grass (High COF)
  - Indoor: wood (low COF) vs Artificial rubberized (High COF)

- Weather
  - Dry conditions (low rainfall, high evaporation) increases COF

Noyes, Westin<2013>
Sportsmetrics

Landing Force

Knee Abduction Moment

Hip Flexion

Knee Flexion Angle

Peak Internal Rotation

Knee Separation Distance

Hip Abduction Angle

Hip Moment

Knee Valgus Angle

GAP 1: Risk Identification Gap

Description: each program address different types of risks
IDEF1: IDENTIFY
DESIGN ALTERNATIVE #1: VISUAL ANALYSIS

• Pros
  – Direct observation or description of injury mechanism
  – Safe, and does not have side effects
  – First or second hand information

• Cons
  – Cannot determine internal structure stresses/strains
  – Has to be one on one or only focus on one at a time
  – Video needs to be reviewed

Myer et. al. <2010>
DESIGN ALTERNATIVE #2: PHYSICAL EXAM

• Pros:
  – Analyze anatomic constraints
  – Measures probability of an ACL tear
  – Visualizes internal structures during time of high strain

• Cons:
  – Does not directly analyze injury mechanism
  – Results can vary
  – Need to train doctors
DESIGN ALTERNATIVE #3: 3D ANALYSIS

• Pros
  – Identify injury mechanism
  – Mimic specific movements that occur during injury.
  – Estimate both kinematics and net kinetics at joint during high risk movements
  – Generally safe
• Cons
  – Need supervision
  – May cause muscle injuries if not used properly
  – Expensive

3D Gait Analysis <2015>
DESIGN ALTERNATIVE #4: 2D ANALYSIS

- **Pros**
  - Athlete performs exercises that have large amounts of force
  - Metrics based
  - Measures valgus and knee flexion

- **Cons**
  - Requires trained personnel
  - Takes time to do analysis on metrics
  - Not as Detailed at 3D

Contemplas GmbH <2015>
IDEF2: MITIGATE
DESIGN ALTERNATIVE #5: TEAM TRAINING

• Pros
  – Decrease horizontal and rotational force to the knee
  – Increase flexion during dynamic moves
  – Measured by number of repetitions and durations
  – Prevent Injury, Enhance Performance (PEP) program
  – Knee Injury Prevention Program (KIPP)

• Cons
  – There are many people
  – The trainer can not be everywhere
  – Some examples will not be relatable to certain athletes
DESIGN ALTERNATIVE #6: PERSONAL TRAINING

• Pros:
  – Personalized exercise routine based on metrics
  – Provides athlete with 1 on 1 training
  – Better take into account q-angle and quad-dominance
  – Better takes care of athletes in varying thresholds of likelihood of an ACLI

• Cons:
  – Adds another time commitment
  – Metrics needed to make best use
DESIGN ALTERNATIVE #7: Virtual Reality Training

• Pros:
  – Flexible to assign mitigation programs to different student athlete

• Cons:
  – Expensive
  – Get dizzy
IDEF3: CONTROL
DESIGN ALTERNATIVE #8: SUPPORTS

• Pros
  – Since Q-angle causes inward horizontal force to the knee, a counter support may be beneficial
  – Reduces strain
  – Remind to use other muscles (donuts in baseball)

• Cons
  – More effective in rehab
  – Some braces have metal or hard plastic, dangerous

BetterBraces <2015>  TheBinderLadies <2013>
DESIGN ALTERNATIVE #9: HEART RATE MONITOR

- **Pros**
  - simple to use and read data from
  - portable, gives feedback to coach if the athlete
  - safe, and does not have side effects
  - Can wear during a sporting event
  - Does not need to be used in a lab

- **Cons**
  - Only monitor fatigue level/heart rate or knee position
  - Can be uncomfortable

Alibaba <2015>
DESIGN ALTERNATIVE #9: KNEE BRACE Monitor

• Pros
  – simple to use and read data from
  – portable, gives feedback to coach if the athlete
  – safe, and does not have side effects

• Cons
  – Knee position brace - new technology
  – Could do nothing
  – Might weaken the knee
  – Uncertainty
## TEST PLAN

<table>
<thead>
<tr>
<th>Test Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional simulation of probability of ACL tear</td>
</tr>
<tr>
<td>Review of distributions for inputs used in simulation</td>
</tr>
<tr>
<td>Comparison of simulation outputs and known statistics</td>
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WBS
### CRITICAL PATH FROM 10/26/2015 – 12/02/2015

<table>
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<tr>
<th>Task</th>
<th>Duration</th>
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<tbody>
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<td>Analysis (Experiment)</td>
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<td>Tue 11/10/15</td>
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<td>Sensitivity testing (Design Alternative testing)</td>
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<td>Trade-off (Utility/Cost)</td>
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