Tri-Axial Hinge Knee Brace

Leader: Conor Sullivan
Communicator: Kevin Knapp
BSAC: Jake Levin
BWIG: Alex Yueh
BPAG: Kaitlyn Reichl

Client: Dr. Sarah Kuehl and Mueller Sports Medicine
Advisor: Dr. Joseph Towles

BME 400, Dept. of Biomedical Engineering
University of Wisconsin – Madison, WI 53706

Abstract

Problem
Mueller Sports Medicine's knee braces are currently on the market to prevent and improve rehabilitation of knee injuries. The current devices use flat, aluminum tri-axial hinges on both lateral sides of the brace to prevent lateral bending and torsion of the knee. Mueller has received numerous complaints regarding the proximal portion of the hinge compared to the body. Due to its linear design, the end of the hinge pinches the thigh, exerting excessive pressure and causing discomfort.

Purpose
The primary purpose of this project is to design a new proximal portion of the hinge which better conforms to the knee-thigh angle (valgus inclination) of the user. This new design needs to be one-size-fits-all, reducing pressure and overall discomfort for all users.

Final Design
To address this problem, two designs were developed. The first design consisted of a Y-Arm which bent at a 20° angle from the tri-axial hinge. This reduced the pressure and discomfort felt by the user. Additionally, the Adjustable design was developed which allowed for a more customized fit.

Client Information

Dr. Sarah Kuehl is a project engineer at Mueller Sports Medicine
Mueller Sports Medicine is a company located in Prairie Du Sac, Wisconsin. They specialize in the prevention and rehabilitation of sports related injuries. Some of their main products are knee braces utilizing the tri-axial hinge.

Introduction

Current Hinge
- Mueller Sports Medicine uses a tri-axial hinge in their knee braces[1]
- Hinge closely simulates the natural motion of the knee joint
- One-size-fits-all
- Provides maximum medial-lateral support
- Made of aluminum
- Allows for 180° of flexion and extension
- Straight profile which causes discomfort

Figure 1: Current knee brace with close-up view of tri-axial hinge

Figure 2: The tri-axial hinge, capable of 180° flexion and extension

Motivation
- $852 million is spent yearly on knee braces[2]
- The market for knee braces is expected to grow by 4.9% by 2018[2]
- Mueller receives 20+ complaints per month regarding discomfort of current model[3]

Anthropometric Data Collection
- Completed literature and experimental research to determine the average leg size[4,5]
- Subjects included females and males, ranging from ages of 18-86
- The further away from the knee, the greater the variability in sizes
- Angle from the knee to the mid-calf was not found to be significant
- Most significant measurement found was the angle from the knee to the mid-thigh
  - Varies between 14° to 28° with an average of 20° for the adult population

Figure 3: The current straight leg model, which does not correspond to the shape of a human leg

Figure 4: Overview of measured leg dimensions

Design Criteria

- Use current tri-axial hinge and modify its arms
- Able to withstand at least 15,000 bends per day for a year
- Withstand a load of 300 lbs per hinge
- Prevent lateral motion and hyperextension of the knee
- Provide normal knee flexion
- Conform more closely to the patient's valgus inclination to mitigate pinching forces
- One-size-fits-all, able to adjust to broad range of leg sizes
- Weight of hinge no more than 4 lbs
- Made of aluminum

Final Design

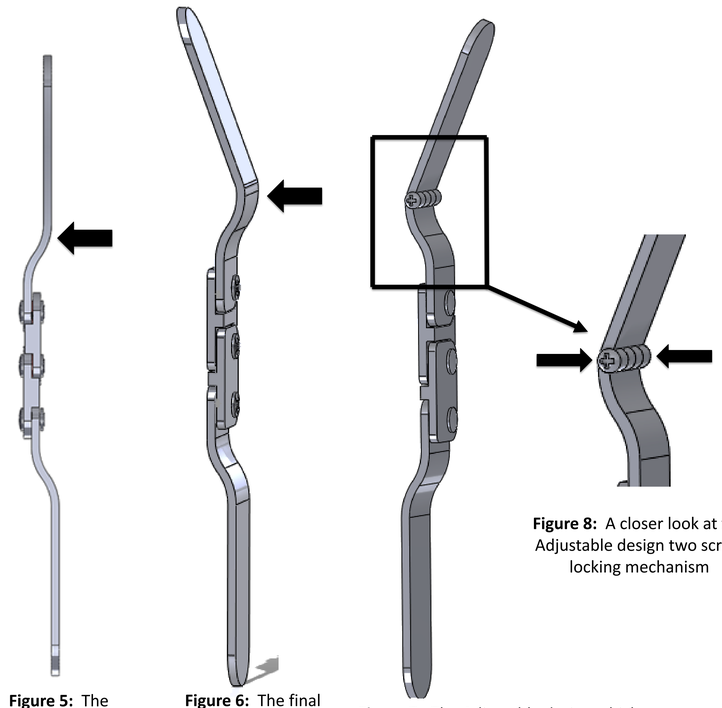


Figure 5: The current design which uses a flat profile against the leg

Figure 6: The final design which includes a Y-Arm that bends away from the leg

Figure 7: The Adjustable design which includes a screw on each side of the hinge, that locks in the angle of the proximal arm

Figure 8: A closer look at the Adjustable design two screw locking mechanism

Static Testing

The Adjustable design failed immediately under low loads, so no further testing was completed. The following tests were only conducted on the Y-Arm.

MTS Testing
- Compressive loading on distal tip of Y-Arm
- Clamp the connecting flat surface
- Max load= 163 lbs
- Ultimate load= 85 lbs

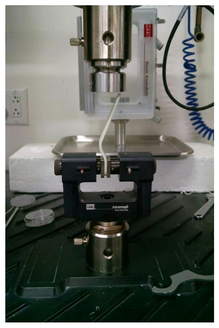


Figure 9: MTS setup of ABSplus plastic prototype

SolidWorks FEA
- FEA was conducted to compare theoretical to experimental values of ABSplus plastic in order to validate 1060 aluminum FEA results

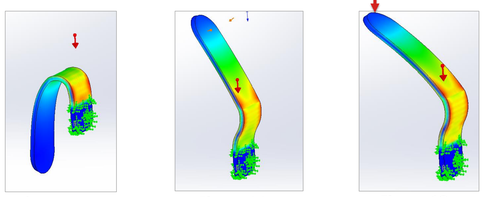


Figure 10: ABSplus at 163 lbs

Figure 11: 1060 Aluminum at 163 lbs

Figure 12: 1060 Aluminum at 300 lbs

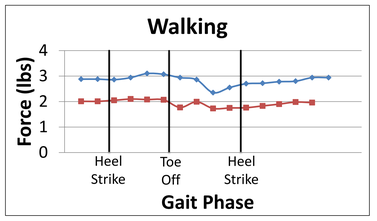
Results
- MTS of ABSplus matched FEA results
  - Blue is low stress, red is high stress
  - Bent until fracture above clamping
- Aluminum should have similar results as ABSplus at higher loads
- **Conclusion:** Aluminum is expected bend long before fracture can occur

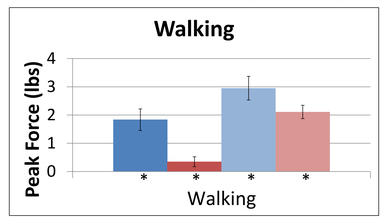
Dynamic Testing

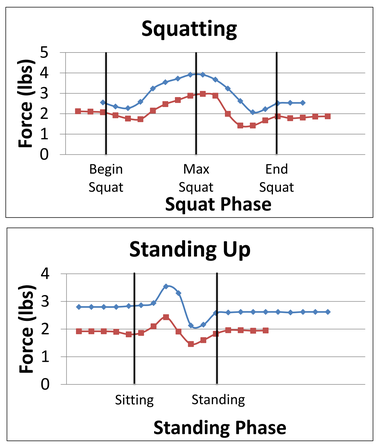
Force Sensitive Resistor (FSR)
- FSRs change resistance when a load is applied
- Used a voltage divider circuit and Arduino Uno to convert voltages to forces

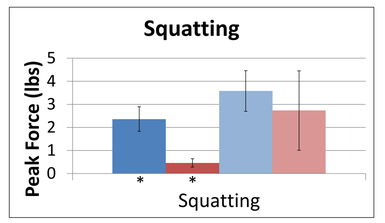
Testing
- Fastened FSRs to the distal tip of the proximal arm
- Monitored forces during walking, squatting, and standing up
- Statistically significant reductions in all but one set of sensors

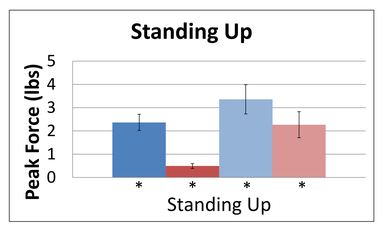
Figure 13: Intertek 402 FSR used to determine the forces exerted on the leg by the hinge











Figures 14-16: Plots showing the change in force over the various movement phases. Straight Arm forces are significantly larger than the Y-Arm forces suggesting our prototype successfully alleviated pressure.

Figures 17-19: Graphs showing the average peak forces for the inside and outside sensors. The * signifies a statistically significant reduction in force.

	Walking	Squatting	Standing Up
Inside Arm	81%	80%	79%
Outside Arm	28%	24%	32%

Table 1: The reduction in force of the Y-arm compared to the Straight arm as a percent

Future Work

- Improve stiffness of the Adjustable hinge to meet design specifications
- Complete dynamic testing on both the Adjustable and Y-Arm designs using Motion Capture and increase sample size
- Improve the knee brace arm sleeve to better fit with the re-designed hinge
- Fabricate final prototype out of aluminum

Acknowledgments

Dr. Sarah Kuehl
Mueller Sports Medicine
Dr. Joseph Towles
Dr. John Puccinelli
The COE Student Shop
Dr. Thomas Yen
Alex Nguyen
All of the BME Resources

References

1. "HG80® Premium Hinged Knee Brace," *Mueller*, 2014. [Online]. Available: http://www.muellersportsmed.com/by-body-part/knee-braces-and-supports/hg80-premium-hinged-knee-brace.html. [Accessed: Oct. 13, 2015].
2. "US Market for Orthopedic Braces and Supports," *PRNewsire*, March 11, 2013. [Online]. Available: http://www.prnewswire.com/news-releases/us-market-for-orthopedic-braces-and-supports-196849711.html. [Accessed: Dec. 8, 2015].
3. "Field Complaints," Mueller Sports Medicine, Prairie Du Sac, Wisconsin, 2014.
4. NASA, "Anthropometry and Biomechanics" in *Man-Systems Integration Standards*, Vol. I. 1995.
5. C.D. Fryar, Q. Gu, C.L. Ogden, "Anthropometric reference data for children and adults: United States, 2007–2010," *National Center for Health Statistics*, vol. 11, no. 252, 2012.

Images
Figure 1: http://www.westcoastmedicalsupply.com/Mueller_Hg80_Hinged_Knee_Brace_p/5401.htm
Figure 13: http://www.interlinkelectronics.com/FSR402.php