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Study of a Woman Athlete's Knee to Prevent Valgus

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ABSTRACT

After the introduction of Title IX, a federal law prohibiting discrimination based on gender, the number of women involved in high school and collegiate level sports has significantly increased. Increasing the number of female athletes has a direct correlation with the amount of injuries experienced by these women. One of the most common injuries to female athletes is a sprain or a tear in the Anterior Cruciate Ligament (ACL) located in the knee. The ACL is one of the main components in the stabilization of the knee. A strain or tear to the ACL causes everyday life to be impacted significantly. ACL injuries are not only debilitating, but are expensive and have long term effects including arthritis.

Women have an increased chance of injuring their ACL for three main reasons: anatomical, hormonal, and biomedical. Statistically, women have wider hips and weaker inner thigh muscles than men. Additionally, women experience changes in hormonal imbalance which contributes to their cyclic changes in ligament strength. Lastly, knees can experience a bio-medical condition known as valgus. The presence of extreme valgus typically indicates a high risk of future ACL injury due to the increased stress on the ligament. Due to these factors, this study involved designing three prophylactic braces to be used as part of a training program to help strengthen the muscles surrounding the knee.

INTRODUCTION

Valgus is a deformity in which one or both knees are bent inwards (Figure 1). The presence of extreme valgus typically indicates a high risk of future ACL injury. Conversely, a varus deformity, causes one or both knees to bend outwards. A non-valgus knee is one in which valgus is not present, i.e. there is no inward motion of the knee during a vertical jump.

Since the 1970's there have been many advances in the bracing of ACLs. One main difference from present day designs is that in the 1970's doctors viewed knees as a standalone element and braced mainly around the injured knee[1]. However, at present doctors view the upper leg, lower leg, and knee as a system. By viewing these elements as a system, braces have become longer and stronger thereby providing support from the upper thigh to the lower leg. This helps to mobilize the knee and distribute the stress along the brace resulting in the ligaments of the knee absorbing less shock and experiencing less stress. Consequently, the braces associated with this research also used a system view of the thigh, knee, and calf. Even though this resulted in an increase in the bulkiness and material weight of the brace, it significantly increased the amount of support to the knee and its ligaments.

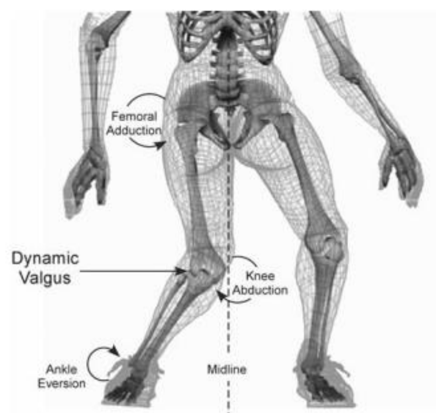

Figure 2 shows a model of the knee designed in NX.

Figure 1: Valgus knee motion

The model was used to compare a valgus versus a non-valgus condition in the knee. Figure 2 shows the amount of stress located in the knee ranging from red to blue, red being the highest stress, with the main stress being located along the center of the ACL. A path was created along the ACL to compare both stress conditions.

In non-contact sports, valgus is a main cause of injury to the ACL. As seen in Figure 3, the amount of stress on the ACL increases significantly in a knee with valgus compared to the non-valgus knee over a normalized distance. By increasing the stress over time, the ligaments in the knee become fatigued, and as a result there is an increased likelihood of injuries, such as tears [2].

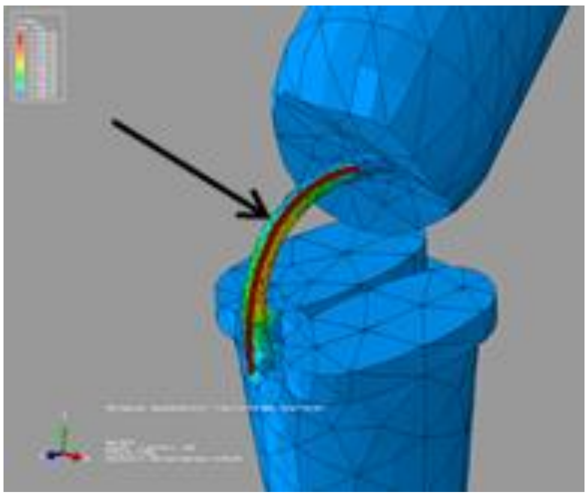

Figure 2: High stress in the ACL the valgus

Modern functional bracing tends to be a hard, two hinge model with supports structured up and down the axes of the leg. Studies have shown that these braces can create moments that counteract varus and potentially valgus in the knee [3]. These braces, however, have not been extensively examined as to whether they will significantly alter body mechanics after use.

In addition, it should be borne in mind that there may be negative effects associated with creating a prophylactic brace. Athletes might injure themselves by believing that the brace can completely protecting them from tears.

Unfortunately, like all braces, bracing can only help lessen the amount and severity of injuries that occur, and not prevent it. The athlete must therefore remember not perform risky sports activities. They must understand that a brace does not substitute for vigorous rehabilitation to improve strength, flexibility, and proprioception. Running with a functional knee brace may lead to increased intracompartmental pressure in the anterior tibial compartment, which may lead to chronic compartment syndrome. Bracing the outside of the knee was thought to minimize tears of the MCL, but it has been suggested that the braces increase stress load on the medial side of the knee and other points of the knee[4]. This is due to the way the brace is constructed and designed.

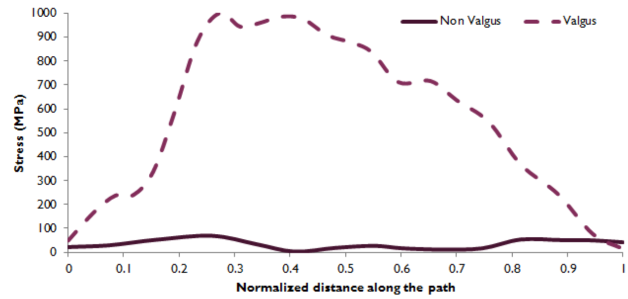

Figure 3: valgus and non-valgus stress in a knee ACL

One study has evaluated the running, jumping, and turning performance with and without a functional brace in 31 patients who had had an ACL reconstruction 5 to 26 months previously. In this study it was observed that there was a significantly better performance without bracing; however, more than half the group experienced an enhanced performance with the brace[4-6]. Consequently, in general, most braces are designed for post injury scenarios, however, the work presented in this study describes a brace that has been designed to prevent injuries by engendering good leg mechanics and strengthening the associated muscles. In the end, this will help save athlete's time, money, and pain, by properly training their body to reduce valgus [2].

LEG GEOMETRY DATA

Before the start of the brace design, data was collected to allow variations in hip and leg measurements between mature females and males to be evaluated. For this study, six different measurements were recorded for 10 female subjects and 10 male subjects. The measurements collected were the width of the hips and five different circumferences around the knee area (Figure 4).

These locations were six inches above the knee, three inches above the knee, at the knee, three inches below the knee, and six inches below the knee. In particular, this data was used to examine the belief that women have wider hips than men. In addition, the data allow the degree of variation in leg size to be established for the 20 subjects.

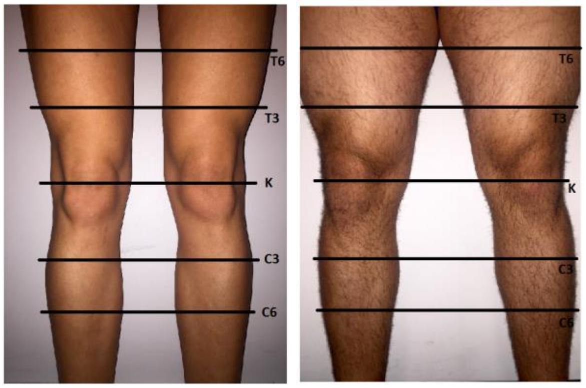

Figure 4: Female (left) and male (right) leg measurement diagrams

From these results, it was determined that the average size of male upper and lower legs is significantly larger than women's upper and lower legs. Additionally the data showed that woman's hips are approximately the same absolute width in comparison to men's hips. This did not appear to match the hypothesis that women typically have larger hips than men. However, the average height of the women was smaller than the men, therefore in relative terms (i.e. with regard to height) the women did have wider hips. Also, a larger test group might show a different absolute statistical pattern.

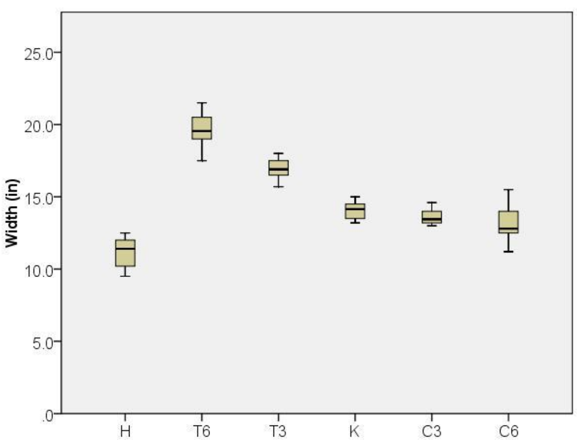

Figure 5: Box and whisker representation of the collected data for female hips and legs

Specifically, for the female measurements, the overall standard deviation was less than 1 in.; however, for the measurements 6 in. above and below the knee the standard deviation was greater than 1 in. (Figure. 5). This is important because it shows that if custom knee braces are to be designed for women, it may only be necessary to customize the sizing at two locations, with these locations being the circumference around the upper thigh and lower calf. In the brace, this would be the top most and lowermost support points. The data therefore showed that a brace must be made parametrically editable and taper in from the thighs to the calves to produce a good fitting brace.

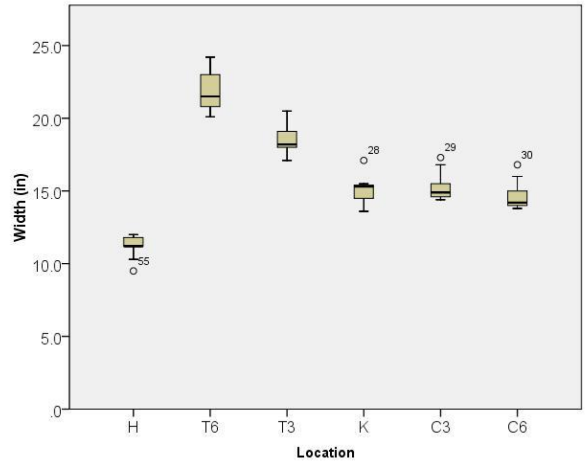

Figure 6: Box and whisker representation of the collected data for male hips and legs

BRACE DESIGN CONSTRAINTS

There is a need for a safe, unrestricting brace that will prevent debilitating ACL injury. Multiple constraints must be kept in mind when designing and manufacturing the brace. The first and primary consideration is to ensure that no further damage is done to the subject. Athletes, and in particular post-injury athletes, tend to become reliant on a brace as a "crutch" or "safety blanket." This leads to an inability to return to peak levels of performance. Thus, the design was constrained in terms of size and comfort, because the brace had to provide the necessary support to ensure correct leg motion while also not providing too much support and thereby restrictive the activity of the athlete. The user must feel as though the brace is providing extra support while engendering correct knee motion; however, they must not feel so constrained that they have to resort to an unnatural motion to accommodate the brace.

The design also had to be simple to allow for ease of construction and repair while minimizing cost, thereby making it available for a broad audience. With this in mind coaches and athletes would have to be able to easily configure and take the brace apart.

Due to these factors, it was decided to create a screening program for college-aged athletes. The program then allowed a prophylactic brace to be designed and used in a training program to help strengthen the muscles surrounding the knee.

SCREENING ATHLETES

College-aged female athletes who are at medium to high risk for ACL injury were identified from both the women's soccer team and the woman's rowing team at Manhattan College. This was done by using a screening test that specifically assesses risk for valgus and ACL injury as described in the Kinesiology textbook JumpMetrics[7]. The test was done on the athlete's dominant leg, which was determined by asking or observing the subjects. The screening test involved six different exercises, which were:

- Single Leg Stance (x3)
- Single Leg Squat (x6)
- Tuck Jump
  - Jump Technique (x6)
  - Landing Technique (x6)
- Single Leg Hop (x6)
- Hamstring Curl (x3)
- Pelvis Lift (Bridge) (x3)

The athlete performing the exercise was observed by at least two researchers, and the subjects were asked to do several repetitions until both researchers had reached a decision about the score. Once all of the exercises were completed, a score was calculated. Based on this score, the athletes were placed into three categories, high risk, medium risk, and low risk. The score of 1-7 implied that the athlete had a high risk for ACL injury, 8-22 implied the athlete had a moderate risk for ACL injury, and 23-28 implied the athlete had a low risk for ACL injury. The most significant test was the tuck jump because it was possible to note if the athlete had a weakness in their dominant leg when they landed.

BRACE MANUFACTURE

The knee brace was 3D printed at Manhattan College using ABS plastic, which was economical to print, with the cost being only $25/kg. Several prototypes were produced and by doing so key manufacturing factors were identified with respect to brace strength and function. In particular, it was found that the printing orientation had a major impact on brace strength. In addition, as was expected, the material density also affected the performance of the brace. These considerations were then taken into account in the final design of the brace that was used in testing.

The final brace model (Figure 7) used a crossing plate and bar joint system. Its dimensions were parametrically editable to allow it to be produced for different leg geometries. Other design changes that were incorporated as a result of the prototype testing were the thickening of the ribs and the change in the top rib geometry from a circular arc to an elliptic shape to allow the brace to fit more snugly onto the upper leg.

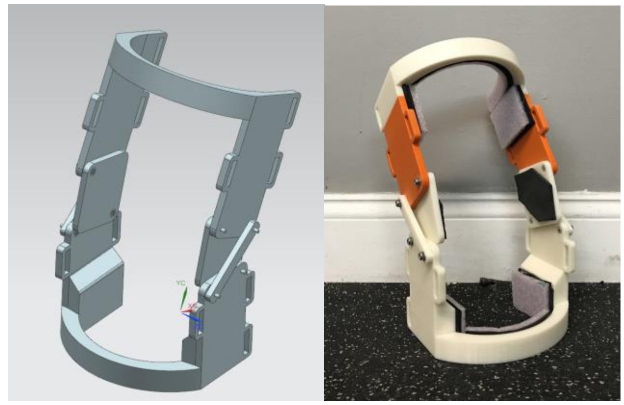

Figure 7: CAD model and actual brace

TRAINING PROGRAM

After the braces were designed and printed, they were used in the training program for the women's soccer team and rowing team. Of the 37 athletes screened only 20 were found to have a moderate to high risk of ACL injury, and this 20 were enrolled in the training program.

The athletes were then split into two groups; a control group and an experimental group. The control group did not use the brace, while the experimental group wore the brace during a training program developed by the Kinesiology Department of Manhattan College, which took 15 minutes per session for 2-3 times a week and for a total of 7 weeks. Since an improvement was anticipated, the difficulty of the exercises was designed to increase over time. In total, this resulted in 30 sessions which was expected to provide enough data to allow any changes in the degree of valgus to be observed.
The eight exercises used are listed below and are identified with the muscle groups the exercises were designed to target. The exercises were chosen because they were expected to eliminate muscle imbalance and promote muscle memory.

EXERCISE LIST

a. <u>Hamstrings</u>
   - Russian hamstring curls
   - Hamstring curls with physio-ball

b. <u>Abductors</u>
   - Side-lying leg lifts

c. <u>Calves/Ankles</u>
   - Single leg balance with heel raise
   - Vertical jumps
   - Squat jumps

d. <u>Abdominals</u>

- Russian twists

e. Balance/Agility
   - Single leg cone touches

RESULT AND DISCUSSION

Prior to the training sessions benchmark results were obtained, which involved recording the athletes performing 10 tuck jumps prior to the first session and again after the last session. From these recordings the landing position was extracted from the video, thereby allowing a comparison to be made of the degree of valgus before and after completing the training program. This was done using image processing software (Matlab).

To facilitate the image processing and minimize the amount of difference between the before and after images, all videos were taken using a tripod set up at the same height in front of the same wall. The participants were also asked to wear the same pants and sneakers that they wore on the first day of training. The image processing program then standardized the size of the picture, and extraneous elements were eliminated using a filter and mask thus allowing the movement of the legs to be isolated (Figure 8).

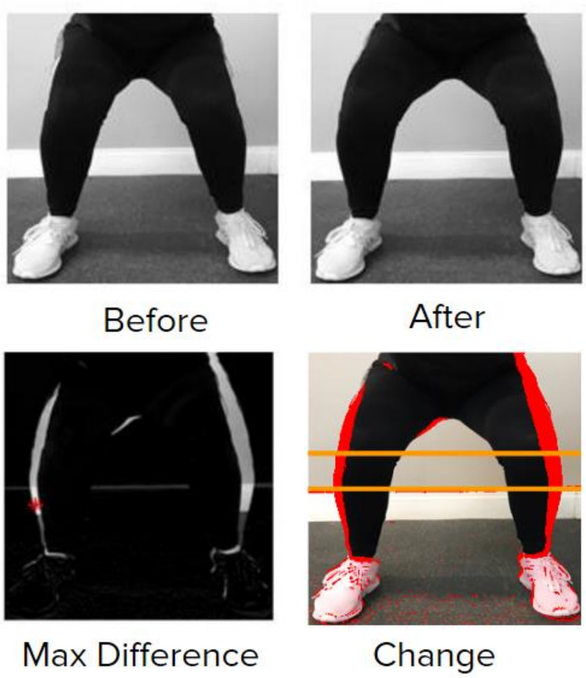

Figure 8: Example of Image Processing

In conclusion it was found that there was a change across the whole leg. This was done by measuring the maximum amount of horizontal change in the knee region by converting from pixels to inches using and appropriated common scale.

This result was the degree to which the knee moved inward or outward in inches, which showed if the valgus increased or decreased. When this was done, the average change in valgus was found to be 0.05 in. However, the average change in valgus for people who wore the brace was equal to the average change in valgus for people who did not wear the brace; therefore the present system has been shown to be ineffective as a prophylactic brace. However, this was a small sample and the testing period was relatively short, therefore more testing will be performed over an extended period of time and for a larger new sample to determine if the program and the brace reduce future ACL injuries.

CONCLUSION

Four parametrically editable braces were 3D printed using ABS plastic and were designed to fit the test subjects of a training program. Out of the 37 athletes screened for valgus, 20 were suitable for testing. These athletes had moderate to high risk of valgus. The athletes then underwent one week of training and their progress was tracked using Image Processing on Matlab. No conclusive results were found possibly due to a short training period.

After implementing the brace in the training program it was discovered that additional improvements could be made to the brace design. Altering the brace design to taper from the thigh to the calf took away the gap between the subject’s knee and the brace, improving comfort and performance. Additionally, the overall weight of the brace was lightened by removing excess material in the form of cutouts. This lighter model increased the comfort and agility of the athlete while performing the training program exercises, and hopefully this will lead to a more successful attempt to decreasing valgus.

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