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Dynamic Ankle Brace

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Abstract

The dynamic ankle brace is a 3D printed brace with geometric mesh patterns and two layers of compression sleeves. The goal of the brace is to design a comfortable slim fit ankle brace that is competitive with current ankle support braces on the market. The geometric braces provided similar levels of inversion and eversion as market braces using different sizing. The braces were tested with a custom built testing rig and human participants proving 3D printed braces are flexible yet durable. User feedback indicates users desired stronger stitching of the braces overall.

Introduction

Ankle injuries are a common problem afflicting many athletes with vast severity. Injuries typically occur when the ligaments stretch to the point of becoming sprained. Ankle sprains range from mild to severe, with mild injuries requiring a couple hours of rest, to the severe injuries that require weeks of bed rest, bracing and support. Many sprains occur during lateral movements such as inversion and eversion which accounts for 62.7 % of all ankle injuries for collegiate athletes [3]. The ligaments affected by such movements are comprised of the Posterior Talofibular Ligament (PTFL), Calcaneofibular Ligament (CFL), and the Anterior Talofibular Ligament (ATFL). The ATFL is the most used resulting in 70% of these injuries [4]. Once an initial ankle sprain has occurred, the chances of another sprain can be increased by up to 61% [5] where it can lead to ankle laxity and other chronic symptoms of pain and swelling [6]. Ankle laxity is where the ankle joint has become loose or unstable, and athletes must compensate for the instability leading to possible injury in the other leg [2].

Many patients must wear preventative measures such as braces and casts to stimulate recovery and prevent the usage of the injured ankle. Braces tend to be better than taping or casts for people [7] as they provide the median between support and functionality. Taping, while providing stability, requires a professional to correctly bind up the joint, and material costs start to add up as the taping tends to be one-time use. Casts are rigid and keep the joint completely in place, but the user finds greatly reduced mobility and lack of comfort. The different types of braces on the market allow for user customization and support depending on injury severity. Braces are listed as class 1 medical devices and can be used during competitions [1]. Braces are divived into four categories: straps, lace-ups, stirrups, and combinations. Straps wrap around the ankle, functioning similarly to taping, however, there is the potential for the brace loosening during usage. Stirrups work similarly to casts where they have rigid plates to hold the joint in place. Lace ups use a lacing system to provide support. Combination braces uses techniques from the other types of braces to cover for design weaknesses. Many market braces are combination types. The Dynamic Ankle Brace team seeks to develop 3D printed braces to limit the ankle's Range Of Motion (ROM), and help facilitate recovery from ankle injuries. These lightweight and thin braces are designed to be worn with shoes, and not hinder performance while still providing some rigidity.

The requirements placed on the brace's design are that the design shall resist motion greater than 40 degrees of inversion, while allowing at least 90% of natural mobility for plantar flexion and dorsiflexion of the ankle. The design of the shell shall be at most 0.5 cm thick. The design of the fabric shall be at most 0.5 cm thick. The application of the brace shall be selfsufficient, taking no more than one minute to put on individually. The design shall be competition legal for competitive soccer leagues in compliance with the International Football Association Board (IFAB) standards.

Methodology

The thickness design requirement is fulfilled by using thin compression sleeves with a thickness of less than 0.3 cm. The braces in development by the team use a lacing system and compression sleeves to provide support, and use Thermoplastic Polyurethane (TPU) for the shell of the braces. TPU is a flexible material that doesn't lose strength over time, resulting in a reusable, washer safe brace. The braces were printed using an Ultimaker s5 and MatterHackers build series TPU. These braces are stitched onto ankle compression sleeves from Amazon, with another pair worn over the braces. Each brace had a geometric pattern so that the braces didn't press against the malleolus of the ankle while still allowing the brace to wrap around the ankle. The triangular mesh created stiff interlocking points so the brace wouldn't break by stretching to fit the user.

Figure 1: Different Sizes of the Ankle Brace

There were two separate testing methods for the braces: one featuring human participants and one using an Ecoflex 00-30 alginate mold.

The model was created by inserting linings and shapes into a container, measuring and mixing water and alginate in a bucket, and transferring it into the container. This was set for ten minutes, then was taken out of the container, and then the mold was cut along the sagittal plane. The skeletal

Figure 2: Solid foam ankle model with silicone weave

model was then put in the mold, the mold combo placed in the box, and a suspension contraction was used to keep the skeletal model in place. The Ecoflex 00-30 was combined with equal parts of its part A and part B mixtures, and the silicone was poured to the top of the mold and set for four hours. After that, the alginate was peeled off, and the excess silicone was cut. These ankle models wear socks and were put in a testing rig.

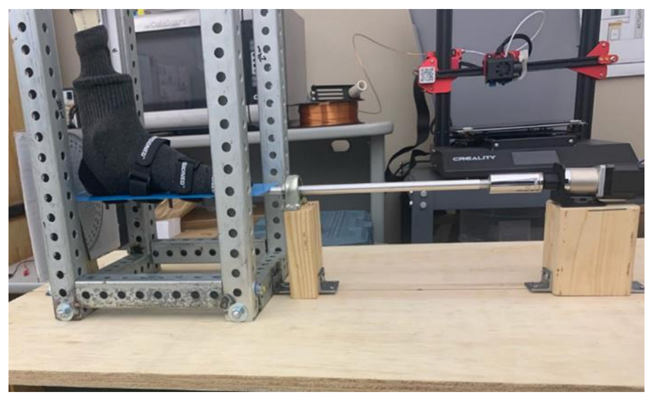

Figure 3: Testing rig setup with ankle model

The testing rig was composed of a foot plate and a rod secured into two sealed bearings. The motor support and foot plate supports were made of 1.5 in by 1.5 in wood blocks, and the bearing housings were attached to the base through a 3.5 in wide, 1.5 in thick, 5 in high piece of wood. There were two vertical supports and a crossbar with the framework made from punched steel square tubing. The vertical supports had tracks to allow two rollers on the crossbar to translate freely on the y-axis. The footplate had slots to allow the model to be strapped down, and allows torque to be transferred through a Nema 17 Stepper Motor and a G251X Step Motor Controller. A 360 degree protractor image is placed behind the model to ensure the same starting angle for every trial. This testing rig tested five types of braces: the team's brace, the ARYSE IFAST, ULTRA Ankle Zoom, DonJoy POD Ankle brace, and the DonJoy ankle compression sleeve. Each of the braces tested prevented inversion/eversion to some degree. The stepper motor turned the rod until the cross bars and braces prevented rotation.

The other testing involved human participants wearing the ankle brace in football practice. First, the participants would perform a stationary task of inversion and eversion with and without the brace. The angle was recorded for multiple iterations to compare how much the brace would restrict their ROM. Then, participants would warm up for a couple of minutes before kicking a standard soccer ball, while wearing the brace. The third task was a pivot task, where the participant would sprint to a marker and then quickly change direction multiple times. This task mimics running patterns during football competitions to ensure the braces did not inhibit kicking ability, nor agility. Finally, the participants would answer a short questionnaire on how the brace felt and if it hindered their abilities.

Results

The results of the testing from the testing rig found that the team's brace was comparable to other market braces. The testing foot had an inversion of 140 degrees and eversion of 95 degrees. That means there is a total ROM of 45 degrees.

Brace	Inversion (degrees)	Eversion (degrees)
Dynamic Ankle Brace	125	85
ARYSE IFAST	115	80
ULTRA Ankle Zoom	120	85
DonJoy POD Ankle brace	115	75
DonJoy ankle compression sleeve	130	90

Table 1: Ankle inversion/eversion comparisons

Each market brace limited the ROM by at least five degrees, with ROMs of 40 degrees or fewer. The dynamic ankle brace had a ROM of 40 degrees. The human side of the testing found that while the braces did help stabilize ankle joints and reduce ROM while moving, the braces started to become ineffective after a short period of time. Many participants found the braces would tighten and press into the feet, leaving marks closer to the lacing. Often, this meant that participants would have to take the braces off early to prevent hurting, as the braces would sometimes break during the pivot task. These breaks would occur not on the brace shell, but on the stitching of the shell to the fabric. All users found the braces comfortable to wear when not doing strong motions, though many found the brace was not easy to put on depending on sizing issues and fear of breaking the stitching. The participants only tested wearing no braces and the braces designed by the team.

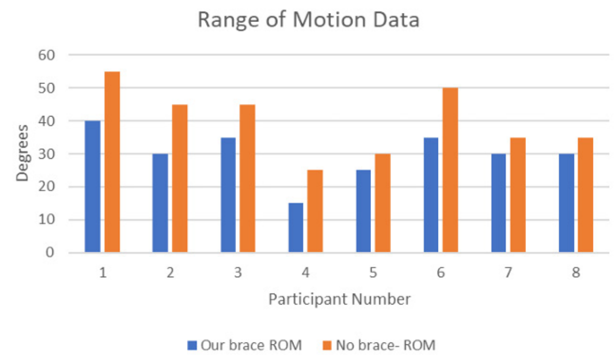

Figure 4: Participant ROMs

In each case, the participants found the brace limited their ROM by five degrees or more. Participants were split on whether they would reuse this brace to prevent injury and reinjury. While the braces were able to resist motion greater than 40 degrees of inversion in both test and real-world settings, further testing is required over multiple subjects and several trials to test conformity. The design allowed at least 90% of natural mobility for plantar flexion and dorsiflexion, with participants only experiencing limitations during inversion and eversion as intended. The design of the shell and fabric were also less than 0.5 cm thick for each material. The design, while being harder to put on than some of the test braces, was still put on below the one-minute time constraint, averaging around 30 seconds to fully put on and tie up. The design is competition legal for football leagues by not having any unlawful materials as defined by the IFAB in it's design.

Discussion

While the braces were able to fit most of the design requirements, the sizing made it difficult to put it on in under one minute. As the participants feared breaking the braces, stronger factory stitching is necessary to ease efficiency in application and usage during strong motions. The braces featured three sizes: small, medium, and large. However, better sizing options are required as the participants still found difficulty due to size issues. When the Dynamic Ankle Braces were compared to the standard market braces, it was found that the Dynamic Ankle Braces were less form fitting. However, the changes in size of the team's braces would allow a larger variety of foot sizes to wear the braces and secure them to people's ankles. The braces performed somewhat according to expectation in limiting ROM, while being flexible and usable for participants. However, they still require stronger materials or a different method of attachment to the compression fabric to use for longer periods of time. Further experimentation should result in braces that are modified to adjust to people's ankles better, and more sizing options to allow feasibility in widespread application.

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