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Optimization of a foot model for the evaluation of the injury risk during cutting movements in football

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Abstract

Cutting movements in football (soccer) induce high loads on the anterior cruciate ligament in the knee. The injury risk is affected by the shoe-surface interaction. For the evaluation of different influencing factors of this interaction the TrakTester, a custom-made device, was used. To obtain significant results from testing ACL loading a realistic plantar pressure distribution in the shoe is required. Using the TrakTester several cutting movements were carried out using two different foot models with the resultant plantar pressure analysed with three different systems: The original foot model with Parotec insoles (24 integrated sensors; Paromed GmbH, Markt Neubeuern, Germany), the modified version of this foot model with Pedar-X insoles (99 sensors**;** novel GmbH, Munich, Germany) and the inflexible model was surveyed with the OpenGo science system (13 sensors, Moticon, Munich, Germany). For the inflexible model distinct angles between the lower leg and the surface were adjusted and the obtained plantar pressure distributions were analyzed. As the first version showed high pressures in the arch region, it was modified to reduce the load in this area. A second inflexible model induced the pressure in the heel and forefoot region. For various angles similar plantar pressure distributions were obtained. Highest pressures were applied on the medial side of the heel and forefoot with minor load in the arch region. This corresponds to literature data investigating cutting movements with subjects. Tests with the inflexible foot model achieved similar and realistic patterns of the plantar pressure distribution for different angles. This is an important precondition to obtain reproducible data for ACL loading during cutting movements.

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Keywords: Football; soccer; football boots; foot model; plantar pressure distribution

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1. Introduction

Football is one of the world's most popular sports and is enjoyed by many through playing at all levels [5]. It is a highly competitive contact sport and the nature of football makes injuries part and parcel of the game. Although contact injuries are generally unavoidable, non-contact injuries are as frequent and severe. Of particular concern are ACL injuries, in which it is one of the most severe non-contact injuries experienced in football.

Most non-contact ACL injuries involve players on the attacking team, especially the player in possession of the ball. Attacking play involves high levels of movement, where quick, sharp changes in direction are key to dribbling past defenders and creating space to attack. Footballers rely on their footwear to provide the necessary traction for optimal performance. Football boot manufacturers have developed different outsoles for football boots to provide traction on a wide range of playing surfaces through varying stud patterns and designs. Stud design has advanced over the years to provide players with increase traction, and excessive traction, especially rotational, can prove detrimental as it increases the risk of ACL injuries [1].

The injury mechanism for non-contact ACL injuries occurring during football has been identified as a planted and fixed foot with slight knee flexion in a valgus-position of the tibia and internal rotation of the body, which occurs during game-relevant situations such as cutting movements and one legged jump landings [2,3]. This suggests that stud-surface interaction is of high importance and a deeper understanding is required to potentially reduce to risk of non-contact ACL injuries.

Custom-made jigs to determine the traction behaviour of football boots have been developed to replicate and provide insight to stud-surface interaction during a game situation. The TrakTester, a custom-made jig developed by Grund *et al.* [3], is currently one of the most advanced as it simulates game-relevant ACL injury situations by applying realistic loadings in anatomical axes of the leg (Fig. 1).

However, to further understand the complex relationship between stud-surface interaction and knee injury, an appropriate loading pattern of the shoe is also required. Hence, the ability to replicate realistic plantar pressure distribution during cutting movements using the TrakTester is vital to achieve significant results and expand the knowledge of this injury mechanism.

Fig. 1. Custom made test jig TrakTester (left) with metal skeleton of the original foot model [3]

2. Method

The TrakTester is a highly developed device used to simulate ACL-risk situations like plant-and-cut-maneuvers. It consists of an artificial foot model with a shaft for the lower leg, all corresponding to realistic human anatomy. Pneumatic devices are used to provide preloads and torques, while rotating frames allow for adjustable angles between the lower leg and the surface in the coronal and sagittal plane to help replicate and analyze cutting movements. The resulting forces and moments in the knee are measured with a 6-component-load-cell, and in combination with a detailed representation of the human knee [4], the loading of the ACL during cutting movements can be determined. Further details on the design of the TrakTester have been published earlier by Grund et al [3].

The original foot model consisted of five different parts linked together to anatomically simulate the complex nature of the human foot (Fig. 1). Two mechanical joints were used for the ankle, one acting in the axis of the talocalcaneal joint and another one for the talocrural joint of the ankle. Plantar tendon steel cables clamped at the heel are fixed on each part and guided along the sole helps determine and maintain the alignment. A silicone mixture with similar mechanical properties to soft tissue was cast in a foot shape around the foot model using a bespoke mould.

The original foot model was revised, with modifications made to ensure a more profound arch region in the sole. This included tensioning the plantar fascia steel cables to create a higher arch, while a used insole was cut and pasted into the arch region of the foot mould to cast a foot shape with a higher arch.

The new foot model was designed without any joints except for the ankle complex which was maintained from the original foot model. In contrast the skeleton consisted of different parts which were connected to form one rigid core. This skeleton was enclosed in the same silicone mixture as the original foot model to represent the soft tissue. The casting mould was newly designed on base of a replica of a human foot (Fig. 2).

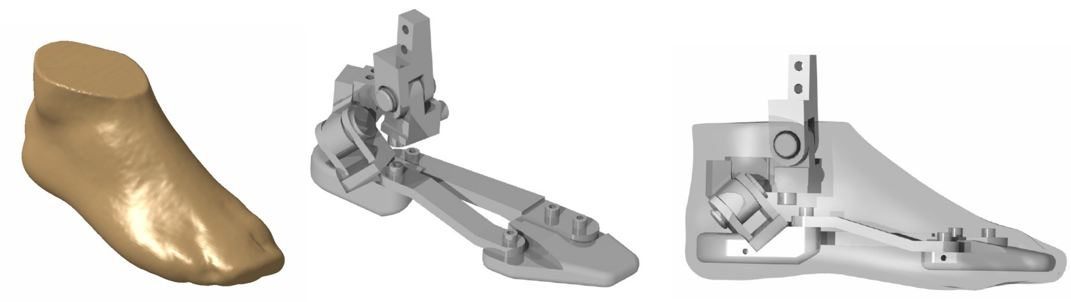

Fig. 2. Development process of new foot model

With the TrakTester each foot model (Fig. 1 and Fig. 2) was tested with several cutting movements performed and the resulting plantar pressure distribution measured. In all cases external plungers were used to assist in applying the proper load on the forefoot region. For the original model up to four plungers were necessary to achieve a realistic plantar pressure distribution, whereas with the new model only one plunger was required. The plantar pressure distribution of the different foot models was analyzed with three different systems:

- The original foot model with Parotec insoles (24 integrated sensors; Paromed GmbH, Markt Neubeuern, Germany)
- The modified version of the original foot model with Pedar-X insoles (99 sensors**;** novel GmbH, Munich, Germany) and
- The inflexible model with the OpenGo science system (13 sensors, Moticon, Munich, Germany)

The plantar pressure distribution obtained from the various foot models were analyzed and compared to literature data [5, 6, 7] and used as a basis for foot model optimization.

Additionally a newly developed Achilles tendon model with four tension springs which are held by a metal construction has been integrated (Fig. 3). To guarantee reproducible results a load cell was integrated to the construction to measure the tensile forces. Furthermore, a separate integrated load cell was added to the existing adjustable plunger for better control of the plantar pressure distributions at the forefoot region. Further cutting movement measurements were performed using the new inflexible foot model set up with their respective plantar pressure distribution analyzed with the OpenGo system.

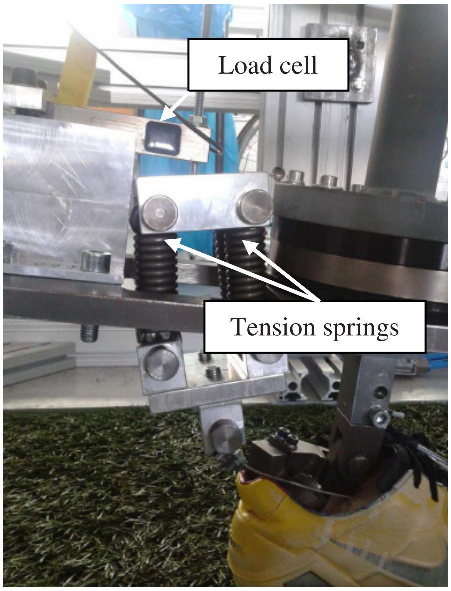

Fig. 3. New Achilles tendon model

3. Results

A comparison of plantar pressure distribution from the different foot models using the various systems for a neutral, 0° set up can be seen in Figure 4.

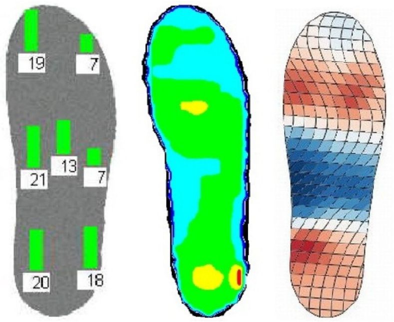

Fig. 4. Pressure distribution at the original foot model (Parotec, left, Grund 2011), the modified model (Pedar-X, middle) and the inflexible model (OpenGo, right)

With the latest developed inflexible foot model, various cutting movement angles produced similar plantar pressure distributions, with a series of results being shown in Figure 5. It can be seen that the highest pressures were applied on the medial side of the heel and forefoot with minor load in the arch region.

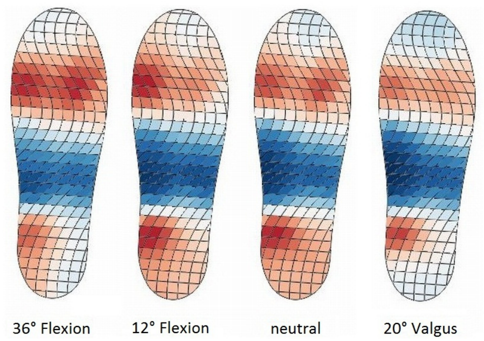

Fig. 5. Similar results of the inflexible model testing different angles between the lower leg and the surface

The same testing parameters were performed with the new Achilles tendon model, with a representation of the full set of results shown in Figure 6.

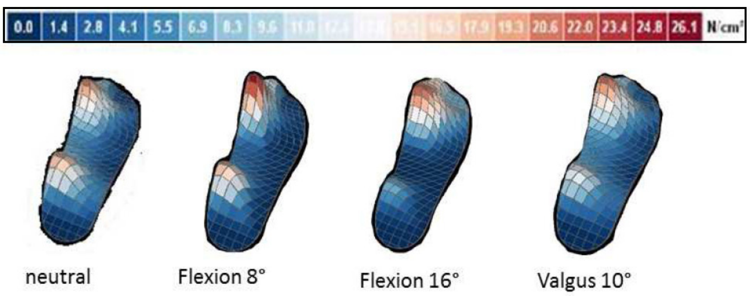

Fig. 6. Plantar pressure distribution with the new Achilles tendon model and the inflexible model

4. Discussion

To gain a deeper understanding of ACL injury risk during cutting movements, it is vital to simulate as realistically as possible the injury mechanism. Hence it was important to achieve a loading condition of the foot as close as possible to the live situation. In this aspect, progress has been made whereby the original foot model of the TrakTester has been continuously updated and optimized to the current inflexible model with the new Achilles tendon.

From Figure 3, it can be seen that the plantar pressure distribution of the original foot model showed high pressures in the arch region, especially in the medial side. This did not correlate with data from literature sources, and hence, the aim of the modified foot model was to reduce the load in this area.

Although the modified foot model could achieve a qualitatively similar plantar pressure distribution to that seen in literature data [5, 6, 7], the design of the mechanical joints in the foot model to achieve flexibility like that of a real human foot meant that it was difficult to consistently achieve a similar plantar pressure distribution, and that an iterative process had to be used. This greatly affected the reproducibility of the plantar pressure distribution, and hence also brought into question the integrity of the test results.

The plantar pressure distribution achieved with the latest foot model (Fig. 6) was qualitatively similar to that seen in literature data [5, 6, 7], whereby the pressure was induced in the heel and forefoot region.

5. Conclusion

There has been a significant amount of progress with the foot model of the TrakTester. Tests with the latest inflexible foot model achieved similar and realistic patterns of the plantar pressure distribution for different cutting movement angles. This is an important precondition to obtain reproducible data for further understanding of ACL loading during cutting movements.

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