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Measurement and Analysis of ground reaction forces Distribution and electromyography for Ankle Joint Fixation Injury Using Different Types of Shoes

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Abstract

One of the health issues that many people encounter on a daily basis is bone fracture, which can happen for a number of reasons, such as arthritis, sprains, or external trauma. The patient experiences instability as a result of these issues. Internal fixation is a type of surgery used to support and mend a damaged bone Treatment options include ankle joint fixation, a surgical procedure employing pins, plates, rods, or screws. This study uses gait analysis methods to assess lower limb biomechanics. Gait analysis is vital for understanding walking patterns and intervention effectiveness. The impact of different shoe designs on ankle mechanics, using the finite element method and ANSYS, is investigated the results of the EMG and the GRF were discussed.

This research deepens our understanding of lower limb biomechanics and ankle joint health. By evaluating stress effects and designing custom shoes, it enhances ankle injury treatment and management strategies.

The patient, a 70-year-old woman with an internal fixation on her ankle joint, underwent a CT scan of her ankle. The patient underwent a number of experiments to evaluate her stability. EMG was used to determine the muscle stress for a brief period of time, and ground reaction force was then used to determine the pressure of walking. Both EMG and GRF have two walking speeds of 1.5 and 2 km/h while wearing four different types of shoes. The behavior of the EMG demonstrates that the stress on the muscle increases as walking speed increases, and the results varies depending on the shoe. The patient is afraid to apply pressure to the injured foot, so the healthy foot has better pressure over the entire, foot. The pressure reaches about 35 N/m². The EMG of the rocker shoe with more damping has less muscle stress, using archfit and rocker gives the best distribution of GRF. Using a rocker gives the best distribution of pressure.

Keywords: Electromyography, Shoe, Ground reaction force, Ankle joint.

قياس وتحليل توزيع قوى رد الفعل الأرضي وتخطيط كهربية العضل لإصابة تثبيت مفصل الكاحل باستخدام أنواع مختلفة من الأحذية

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الخلاصه:

احدى المشكلات الصحية التي يواجهها الكثير من الأشخاص يوميًا هي كسر العظام، والذي يمكن أن يحدث لعدد من الأسباب، مثل التهاب المفاصل أو الالتواء أو الصدمات الخارجية. يعاني المريض من عدم الاستقرار نتيجة لهذه المشكلات. التثبيت الداخلي هو نوع من الجراحة المستخدمة لدعم وإصلاح العظام التالفة. تشمل خيارات العلاج تثبيت مفصل الكاحل، وهو إجراء جراحي يستخدم دبابيس أو ألواح أو قضبان أو براغي. تستخدم هذه الدراسة أساليب تحليل المشية لتقييم الميكانيكا الحيوية للأطراف السفلية. يعد تحليل المشية أمرًا حيويًا لفهم أنماط المشي وفعالية التدخل. تم دراسة تأثير تصميات الأحذية المختلفة على ميكانيكا الكاحل، وتمت مناقشة نتائج (EMG) و (GRF) ,باستخدام طريقة العناصر المحدودة وبرنامج ANSYS، يعمق هذا البحث فهمنا للميكانيكا الحيوية للأطراف السفلية وصحة مفصل الكاحل. ومن خلال تقييم تأثيرات الإجهاد وتصميم أحذية مخصصة، فإنه يعزز استراتيجيات علاج إصابات الكاحل وإدارتها.

خضعت المريضة، وهي امرأة تبلغ من العمر ٧٠ عامًا، تعاني من تثبيت داخلي لمفصل الكاحل، لفحص مقطعي لكاحلها. خضعت المريضة لعدد من التجارب لتقييم ثباتها. تم استخدام مخطط كهربية العضل (EMG) لتحديد إجهاد العضلات لفترة وجيزة من الزمن، ثم تم استخدام قوة رد الفعل الأرضي لتحديد ضغط المشي. يتمتع كل من EMG وGRF بسرعتين للمشي تبلغ ١,٥ و٢ كم/ساعة أثناء ارتداء أربعة أنواع مختلفة من الأحذية. ويبين سلوك مخطط العضل العضلي أن الضغط الواقع على العضلة يزداد مع زيادة سرعة المشي، وتختلف النتائج باختلاف الحذاء. يخشى المريض الضغط على القدم المصابة، وبالتالي فإن القدم الصحية لديها ضغط أفضل على القدم بأكملها. القدم. يصل الضغط إلى حوالي ٣٥ نيوتن/م٢. إن EMG للحذاء الهزاز مع المزيد من التخميد لديه إجهاد عضلي أقل، استخدام القوس المتأرجح والروك يعطي أفضل توزيع لـ GRF. استخدام الروك يعطي أفضل توزيع للضغط.

1. Introduction:

The lower limb, often called the leg, is a fundamental component of human mobility, encompassing the region between the hip bone and the ankle. This intricate lower extremity comprises distinct segments: the thigh, knee, leg, ankle, and foot. Specifically, the upper leg extends from the hip bone to the knee joint, while the lower extremity spans from the knee joint to the ankle joint.

The human foot is a marvel of anatomical engineering within this complex lower limb. The foot epitomises biomechanical excellence, comprising 28 bones 33 joints, reinforced by 112 ligaments, and powered by 21 muscles [1]. Central to its function is the talocrural joint, commonly known as the ankle joint, formed by the convergence of the fibula, tibia, and talus. This joint is pivotal in transmitting forces during motion between the lower leg and the foot, facilitating seamless locomotion.

The lower limb is susceptible to ankle joint injuries despite its remarkable design. These injuries often result from excessive flexion beyond the physiological range and can occur during sports, walking on uneven surfaces, wearing improper footwear, falls, impacts, rotations, or due to pre-existing conditions like arthritis. Ankle injuries disrupt daily activities, emphasizing the importance of effective understanding and management [2].

Treatment is crucial for ankle injuries, with options including ankle joint fixation and replacement. Ankle joint fixation, a surgical procedure, involves using pins, plates, rods, or screws to mend fractured bones within the foot or ankle. External fixation provides stability through external devices that immobilize and support fractured bones [3].

Gait, the ability to walk, is a fundamental skill honed during childhood. It involves coordinated limb motion, neural signaling, sensory inputs, and real-time adjustments to factors like speed and terrain [4]. Gait analysis, a systematic process, observes, documents, and evaluates locomotor patterns during walking. Its objectives include understanding normal gait, identifying impairments leading to mobility issues, and assessing intervention effectiveness [5].

Two primary methodologies stand out in gait analysis: the cause-and-effect technique (top-down) and inverse dynamics (bottom-up). The former starts with sensory data processed by the central nervous system, leading to muscle contractions, joint forces, and ground reaction forces, governing the gait cycle. In contrast, inverse dynamics begins with data collection on ground reaction forces, joint angles, and other parameters using various technologies. Dynamic equations are then used to analyze force transmission [6].

The gait cycle, the rhythmic limb motion during walking, comprises stance (foot grounded) and swing (foot mid-air) phases. Stance includes single support (one foot) and double support (both feet) periods, further divided into stages like initial contact, loading response, midstance, terminal stance, pre-swing, initial swing, midswing, and terminal swing [7]. Spatio-temporal parameters like step length, stride length, stride time, cadence, gait speed, and step width quantify gait nuances.

The study's objectives encompass investigating leg stability, EMG effects during walking, ground reaction forces, numerical analysis via Ansys, and designing custom shoes to meet patient-specific needs based on the parameters studied.

2. Literature Review

This literature review encompasses several studies on the relationship between lower limb injuries, footwear, and athletic performance. These studies collectively highlight the importance of understanding how various factors, including footwear types, playing surfaces, biomechanics, and athletic tasks, influence lower extremity injuries and athletic performance.

Sijbrandij 2002: This study emphasizes the relationship between lower limb injuries in football players and the dimensions, configuration, and distribution of cleats, as well as their interaction with the playing field. It underscores the need for a systematic approach to understanding this relationship, starting from foundational aspects [8].

Hreljac 2004: This study delves into the relationship between Subchondral Cortical Trabecular (SCT) bone structure and knee injuries, particularly ACL injuries. It discusses how factors like running speed and SCT structure can impact knee joint mechanics [9].

3. Experimental work

Using four types of shoes as shown in figure (1) to measure both EMG and GRF have an effect on the ankle joint. The test was done with two speeds (1.5 and 2 km/h), the types of shoes are listed in table (1).

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(A)

(B)

(C)

(D)

Figure (1): Types of shoes a- Foam b- Arch fit c- Air cool d-Rocker shoe.

Table (1): The experimental parameter list.

No.	Speed (km/h)	Type of shoe	Symbol
1	1.5	Foam	P.E. 1
2	2	Foam	P.E. 2
3	1.5	Air cool	P.E. 3
4	2	Air cool	P.E. 4
5	1.5	Arch fit	P.E. 5
6	2	Arch fit	P.E. 6
7	1.5	Rocker	P.E. 7
8	2	Rocker	P.E. 8

3.1 Plate – Force Test:

The ground reaction force (GRF) introduced under the sole, due to biomechanical effects on the leg during gait and stance cases, can be done for a patient who has drop foot using a fixed plate and moving belt devices called "ZEBRIS" connected to the computer as shown in figures 2, 3 and 4. The patient walking over a fixed plate wearing new shoes is clearly shown in Figure 2.

Figure (2): Fixed plate device

Figure (3): Trade mill

over the identical epoch. The schemes show the model's performance throughout ten epochs during the training and testing stages. The data was split into two parts with 80% for training and 20% for testing.

Figure (4): Walking patient

3.2 Electromyography (EMG)

In this study, we only focused on the stance phase of the parameter. Compared to the swing phase, the effect of extra mass of the foot segment on gait dynamics is a minimal instance. If the swing phase of gait is investigated in future research, this issue should be considered. Another limitation was the participants' short adaptation time with the rocker shoes. The current study only assessed the short-term effects of rocker shoes.

The stress on the muscle on the ankle joint has been measured using a sensor that has been fixed to the patient as shown in Figure 5, the procedure is done by fixing the sensor on the ankle joint then the patient has to walk with two different speed (1.5, 2) km / h to measure the stress that happened to the muscle and to know which shoes are better with walking the trade mill as shown in figure 3 and 4.

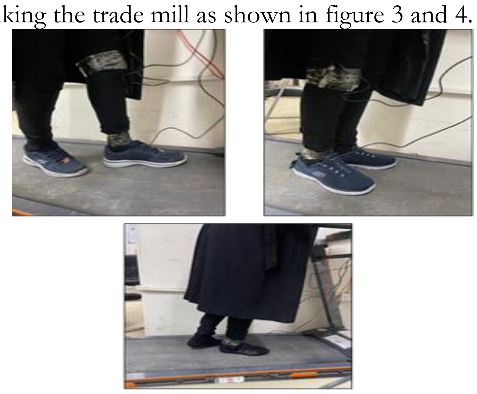

Figure (5): Patient leg with fixed sensor.

3.3 (EMG) Results

Figures 6 to 13 consider the EMG with different shoes that affect ankle joints.

Figure 6 has smooth behavior due to the angle of entrance and exit in the motion is little that can reduce the load on the ankle joint so the maximum 320 μV.

In Figure 7 the movement of the ankle joint was good and the differentiation in the load that happened on the ankle joint gradually increased so the maximum reached 350 μV.

Figure 8 and Figure 9 show that the entrance cause must load on the patient, in this case, the patient's movement is like other shoes due to the shoe design that causes the load in the entrance.

Figure 10 Because the shoe's damping the ankle joint's motion and load on it become lower than other shoes, the load is reduced over the gait cycle.

Figure 13 has a different behavior as compared with other figures due to the instability of the motion of the patient that has more loads with time.

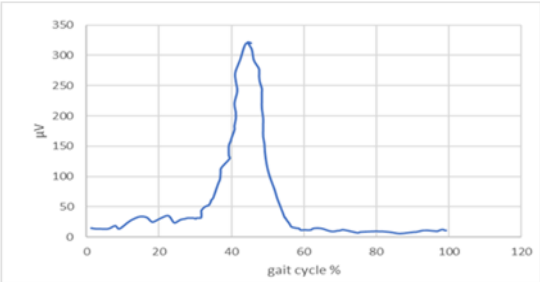

Figure (6): EMG for P.E. 1(foam shoe)

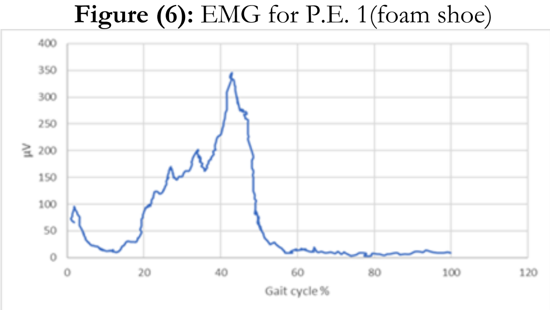

Figure (7): EMG for P.E. 2 (foam shoe)

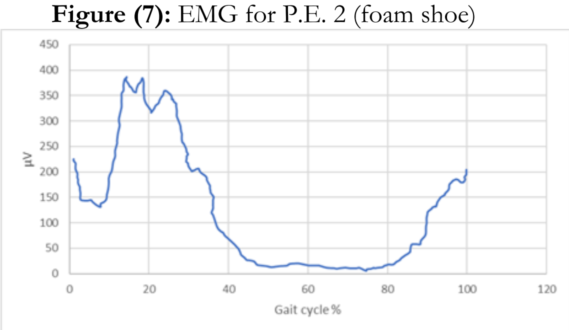

Figure (8): EMG for P.E. 3 (Air cool shoe)

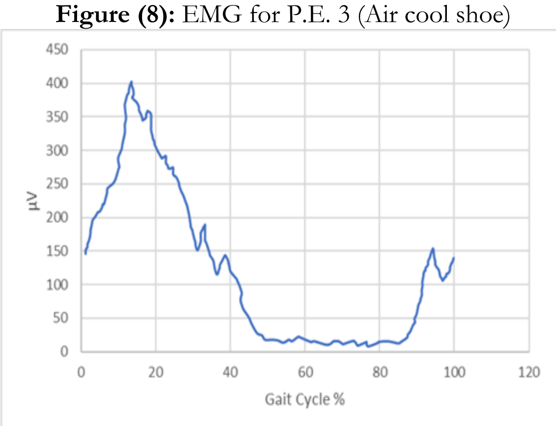

Figure (9): EMG for P.E. 4 (Air cool shoe)

Figure (10): EMG for P.E. 5 (Arch fit shoe)

Figure (11): EMG for P.E. 6 (Arch fit shoe)

Figure (12): EMG for P.E. 7 (Rocker shoe)

Figure (13): EMG for P.E. 8 (Rocker shoe)

3.4 Ground reaction force (GRF) results

The reaction force of the patient's foot has been taken, and the maximum force and pressure have been plotted in Figure 14 to Figure 22.

The GRF of the foot is taken using different shoes, the reaction force of the foot is important to know the distribution of forces and pressure.

The GRF in figure shoeless has unstable force distribution due to no shoes being used in this experiment foot has many force on the arch and ball of foot due to the foot having noting wear in this condition and the patient is walking uncomfortable.

Figure 19 and 20 show the best force distribution because the design of the shoes (arch fit) has the best distribution and design that help the foot to walk smoothly as compared with other types of shoes.

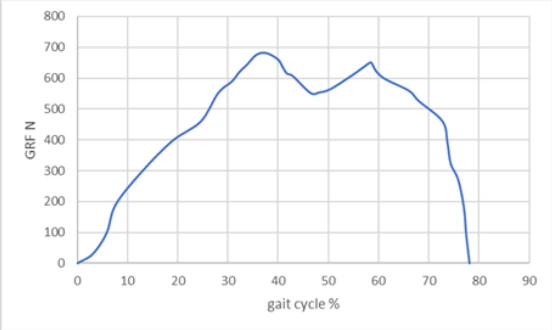

Figure (14): GRF shoeless

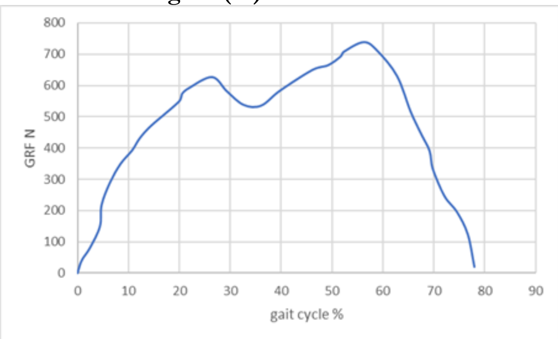

Figure (15): GRF for P.E. 1 (foam shoe)

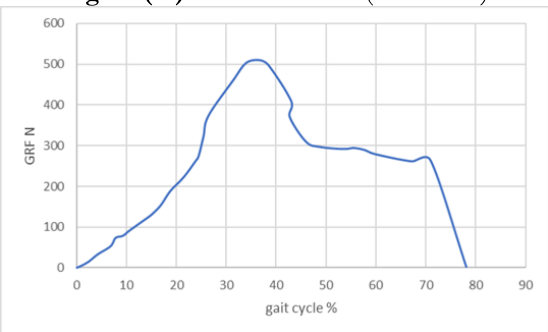

Figure (16): GRF for P.E. 2 (foam shoe)

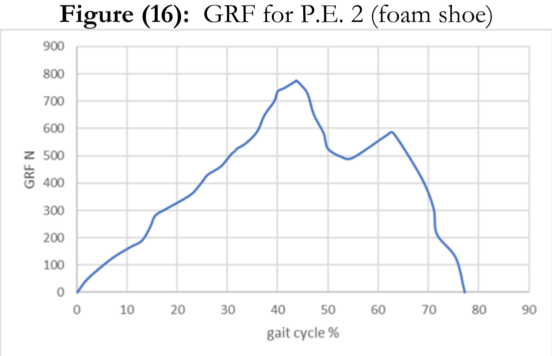

Figure (17): GRF for P.E. 3 (Air cool)

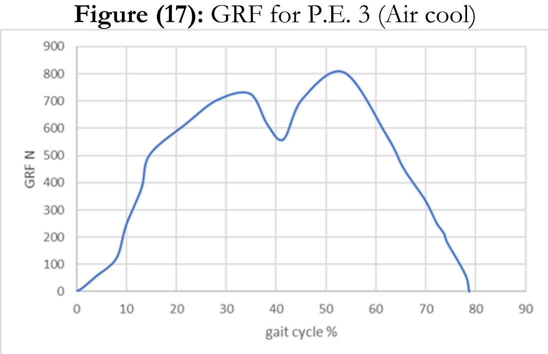

Figure (18): GRF for P.E. 4 (Air cool)

Figure (19): GRF for P.E. 5 (Arch fit)

Figure (20): GRF for P.E. 6 (Arch fit)

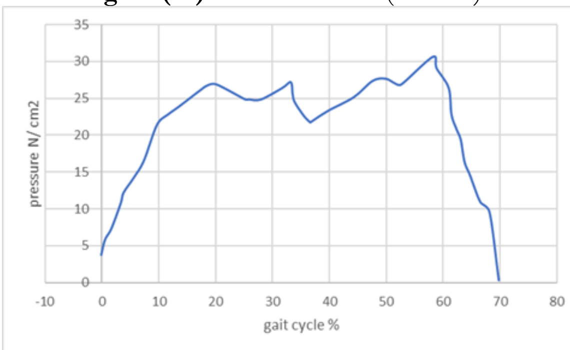

Figure (21): GRF for P.E. 7 (Rocker shoe)

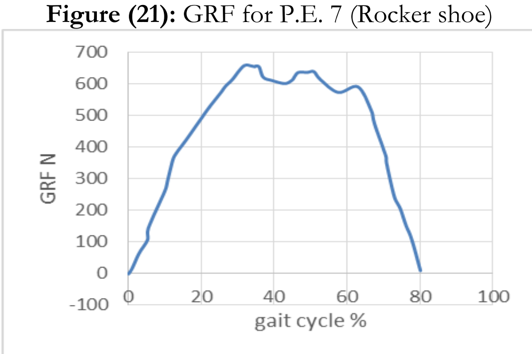

Figure (22): GRF for P.E. 8 (Rocker shoe)

3.5 Ground reaction pressure (GRP) results

The pressure distribution of the shoes is important because of weight of the body must be distributed so that forces on the foot cause exhaustion to the foot and patient.

Figures 23 to 31 show the pressure distribution for different cases with and without using different shoes.

The pressure distribution on arch-fit shoes in Figures 30 and 31 is so clear that the pressure is becoming less due to good GRF distribution.

The stability of arch-fit shoes is so smooth that the pressure is coming down from 35 to 16 N/cm² in arch-fit shoes.

The figure shoeless shows no shoes so the pressure distribution is poor and the value of pressure is up to 35 N/cm². The stability of the patient walking is so important to the ground reaction force and pressure because the patient must walk right on the tride mill that pressure focus to make the patient uncomfortable so the walking on the tride mill will become unstable. So, it is very important to choose comfortable shoes for patients.

Figure (23): GRP shoeless

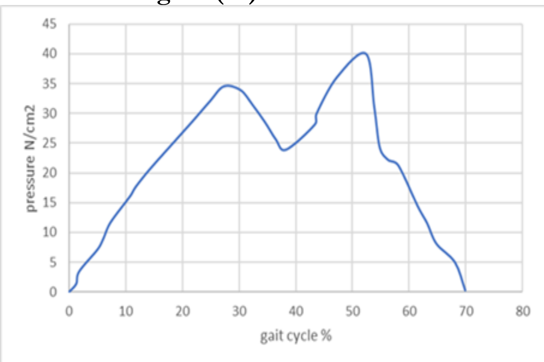

Figure (24): GRP for P.E.1(foam shoe)

Figure (25): GRP for P.E.2 (foam shoe)

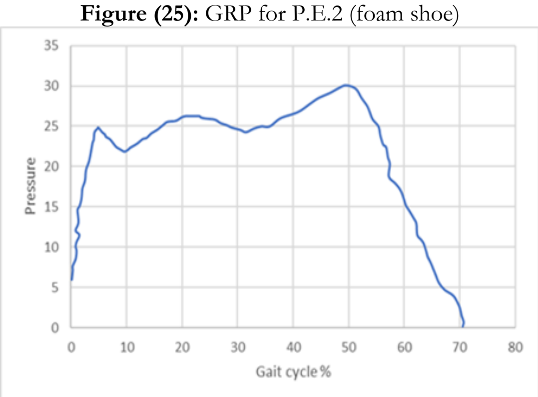

Figure (26): GRP for P.E.3(Air cool shoe)

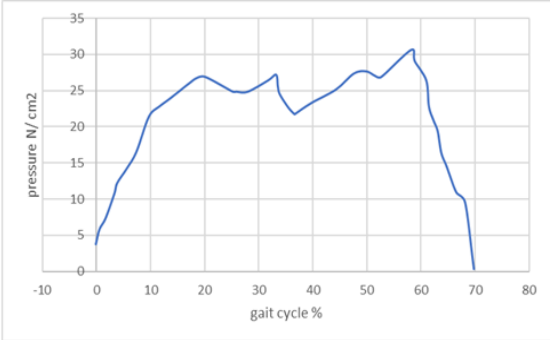

Figure (27): GRP for P.E.4 (Air cool shoe)

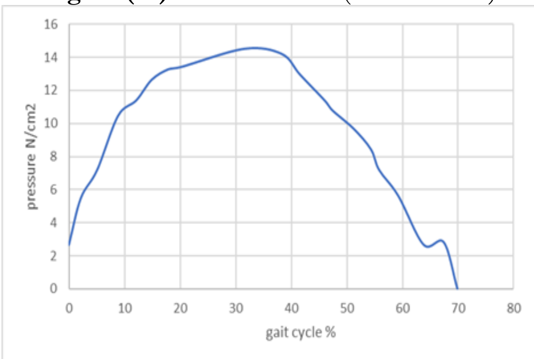

Figure (28): GRP for P.E.5 (Arch fit shoe)

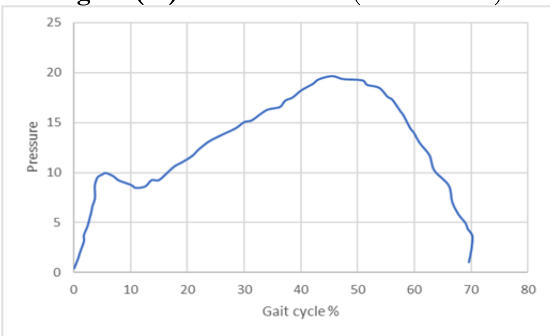

Figure (29): GRP for P.E.6 (Arch fit shoe)

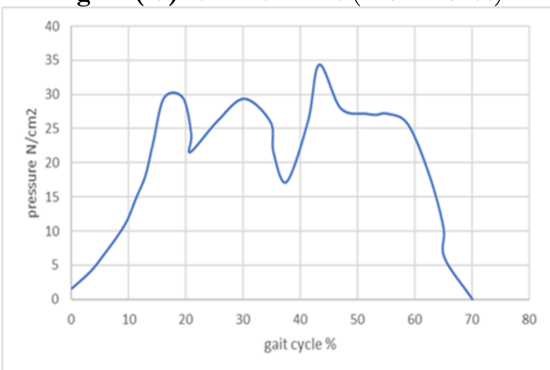

Figure (30): GRP for P.E.7 (Rocker shoe)

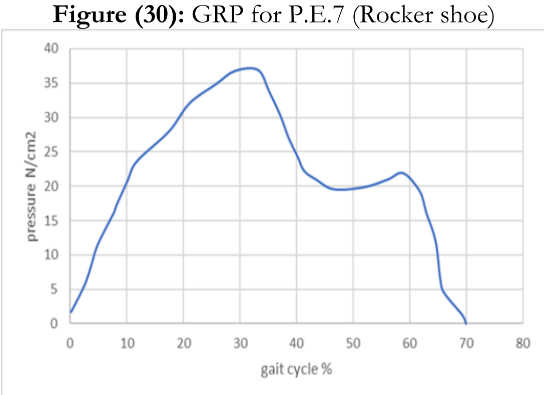

Figure (31): GRP for P.E.8 (Rocker shoe)

4. Conclusion

This study showcases the positive impact of the newly designed ankle joint, both in terms of mechanical performance and injury prevention. The findings of this study can be listed as follows:

1-The movement of the ankle joint depends on angle movement and damping

2-The ground reaction force of the healthy foot is more stable in comparison with the defective foot.

3-The EMG of the rocker shoe with more damping has less muscle stress.

4-Using arch-fit and rocker gives the best distribution of GRF.

5- Using a rocker gives the best distribution of pressure.

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