ASSOCIATIONS BETWEEN ANKLE INSTABILITY AND WEIGHT DISTRIBUTION IN THE FEET

Emilis Kuzminas
UAB PesPlanus
Lithuania

Ramunė Komžienė, Asta Markauskienė, Milda Žukauskienė
Vilniaus kolegija / Higher Education Institution
Lithuania

Annotation

Damage of the ankle ligaments is a common injury that, if untreated or sustained repeatedly, can lead to chronic ankle joint instability. The aim of the study was to evaluate the associations between ankle instability and plantar pressure distribution. 20 physically active, young people underwent a plantar pressure measurement on a treadmill with an integrated sensor system. When the results were compared it was discovered that higher plantar pressure was found in the outer part of the foot when standing, walking, and running in unstable ankles and less pressure distribution in the inner part of the foot.

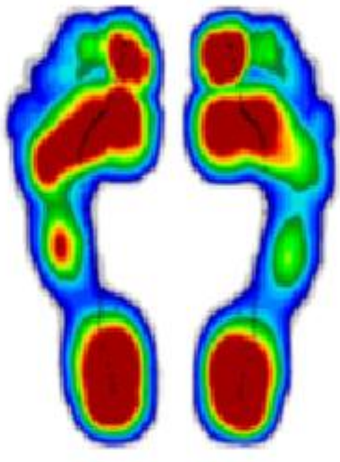
Key words: *ankle instability; feet pressure distribution.*

The human foot is part of a biomechanical chain, where each limb depends on each other. It is therefore sometimes difficult to understand the cause of certain foot and ankle pathologies, as well as the biomechanical abnormalities that occur after a therapeutic intervention. Nevertheless, a thorough understanding of the anatomy and biomechanical principles is essential for a successful treatment of foot and ankle injuries, as well as improving athletic performance [1].

The foot is a complex structure composed of 26 bones, 33 joints, and more than 100 muscles, tendons, and ligaments. These structures are crucial for movement, they work together to provide support, stability, and propulsion during movement and which enable the foot to be both rigid and flexible. The foot makes first contact with the surface during propping with three points of support: the tuberosity of the calcaneus at the rear and the heads of the big toe and little toe at the front. As a separate mechanical part of the leg, it adapts to different or changing conditions and is thus able to provide stability. The ankle joint complex consists of the lower leg and foot, forming the kinetic chain which allows the lower limb to interact with the ground, an integral part of the human part of everyday activities. The ankle joint is also subjected to a high load, and it has been estimated that the force on the ankle joint during movement is about five times the total body weight. The ankle complex is formed by the compound articulations of the talocrural, distal tibiofibular, and subtalar, and is kept stable by the joints and ligaments. The back of the foot consists of the calcaneus, talus, tibia and fibula. These bones and the adjacent soft tissues together form the inner, outer longitudinal and transverse arches. The joint is stabilized by several ligaments, including the medial and lateral collateral ligaments, which help prevent excessive inward or outward movement of the ankle joint. The structural arrangement of the bones and tissues of the foot is thought to be closely related to foot function [2] [3]. The main function remains to ensure the stability and mobility of the foot during exercise. During walking and running, the foot undergoes a series of complex movements that involve dorsiflexion, plantarflexion, inversion, and eversion. These movements are controlled by the muscles and tendons in the foot, as well as the ankle and lower leg. During gait, the ankle joint plays an important role in providing stability and propulsion [4]. The ankle plantarflexes at heel strike, allowing the foot to absorb shock, and then dorsiflexes during the stance phase to allow for the foot to clear the ground. Despite the heavy loads imposed by walking or running, the ankle's bony, muscular and ligament structures allow it to function in a very stable way compared to other joints (hips, knees), the ankle joint seems to be less vulnerable to degenerative processes, unless caused by previous injuries or diseases [5]. During gait, the loads on the ankle joint reach up to four times the body weight. During running, ankle forces are estimated to be up to 14 times higher than body weight [1]. Most of the time the foot is on the ground during the gait, so the movements take place in a closed kinetic chain, while the higher parts of the limb are free to move. Therefore, the foot and ankle movement cause movement of the tibia and fibula, which is transmitted to the femur and hip, if not absorbed by the knee joint. This means that any movement of the foot and movement of the ankle joint should also be considered in relation to the influence of that movement or position to the whole leg. For example, pronation at the ankle joint causes internal rotation of the lower leg and knee, and (valgus) leg position [6]. Acute instability of the ankle joint and lateral ligaments of the calcaneal joint injury is a common injury in young and active people, which can cause long-term impairment in recreational or other active activities. Although these injuries can be effectively treated conservatively, it has been reported that as many as 20-40% of cases can develop into chronic ankle instability.

55% of injuries leading to ankle instability are due to sports injuries [1]. Certain sports require more than good sports technique and training plan. During active movements, the biomechanical requirements of the foot and ankle parameters are much higher. Many of foot and ankle injuries are related to abnormal foot and ankle biomechanics, which can lead to increased stress and strain on the muscles, ligaments, and bones in the foot and ankle. That is why even minor deformities and deviations that normally do not cause any problems, can be the cause of specific injuries or compensatory effects created during movement. It was found that runners with high arches were at a greater risk of developing plantar fasciitis, while those with flat feet were more likely to experience knee pain [7]. Another study showed that runners who overpronated had a higher risk of developing tibial stress fractures [8]. It was also found, that athletes with ankle instability had a greater risk of developing ankle sprains [9] and runners with a history of ankle sprains had weaker ankle dorsiflexion strength compared to those without a history of ankle sprains [10]. Sports that require frequent changes in direction or jumping, such as basketball, volleyball, and soccer, are particularly prone to ankle instability injuries [11]. Ankle sprains accounted for 26% of all injuries, and players with a history of ankle sprains were more likely to suffer additional ankle sprains. Additionally, players who had poor balance and strength in their ankle muscles had a higher risk of ankle sprains [12]. Recurrent ankle sprains and inadequate or no treatment can lead to ankle ligament instability, progressive post-traumatic ankle arthrosis or articular cartilage damage [13]. The effectiveness of a neuromuscular training program in preventing ankle sprains in young athletes significantly reduced the risk of ankle sprains in the athletes [14]. Treatment options include physiotherapy to improve strength and balance, bracing or taping to provide additional support, and in some cases, surgical intervention to repair or reconstruct the damaged ligaments [15].

Chronic ankle instability (CAI) leads to recurrent ankle misalignments, fear of loading the joint, persistent symptoms such as pain, swelling, limited motion, weakness, and diminished self-reported function resulting inappropriate distribution of loads and centre of gravity in the feet during propping [16]. Weight distribution in the feet is little studied in people with CAI, and frequent tibiofemoral misalignments are strongly associated with inadequate weight distribution in the feet (1 fig.).



1 figure. Pressure distribution in the feet in left ankle instability

An analysis of scientific articles investigating the distribution of pressure and loads in the feet shows that in people with CAI, loads are unevenly distributed in the feet due to altered gait mechanisms [17]. The increased loads on the outer part of the foot may be due to reduced activation of the hamstrings during the gait in the stance phase due to sensorimotor disturbances associated with trauma to that joint. In contrast, a reduction in the activity of these muscles at the time of the first contact with the surface may result in an inward rotation of the foot [18].

Although the distribution of pressure in the feet is highly individual, different studies have found that patterns of pressure in foot are quite similar [19]. The heel area is the most stressed, the foot the forefoot and the big toe area, while the midfoot and the lateral toe areas have the lowest load during gait. The pressure under the heel is highest in the early stance phase and at the plantar at the heads of the pads in the late stance phase. In healthy people, the highest loads during movement were recorded at the big toe and the head of the second metatarsal, with slightly less load on the heel the heads of the third and first metatarsals. These are followed by the forefoot and the midfoot the outermost part of the foot and toe zones 2-5 are the least loaded according to studies [20]. The centre of gravity movement path usually starts from the outer heel and ends at the first and second toe spacing, as well as in the dynamics of weight the centre of gravity trajectory tends to shift more inwards [21]. When assessing patients, atypical load distributions may reflect systemic or localised lower limb pathology [22]. This measure can also be used to differentiate between normal and pathological gait, to tailor orthotic devices, and to identify various foot deformities [20]. Foot pathologies adversely affect foot function, leading to impaired movement in everyday life activities and quality of life may be affected. These pathologies are often caused by pain and abnormal weight distribution in the foot, which can lead to pressure between the two feet asymmetrical. Currently, there is no consensus on asymmetry in regular gait, and a standardised method of quantifying asymmetry is needed to assess the loads on the feet method of asymmetry assessment [23]. In people with chronic ankle instability, pressure and loads in the foot are distributed more in the outer part of the foot [18, 24-26]. Only one study found no significant differences in centre of gravity/centre of pressure shift, but this study was conducted in a static position rather than in dynamics, the centre of gravity shift at the outer part was only observed during locomotion, but since muscle activity was studied, a decrease in the activity of the peroneal muscle group in the unstable ankles was found [25]. Similarly, the results obtained by Morrison et al. [24] show a higher degree of heel inversion and reduced eversion in a group of subjects with ankle joint instability, explaining the recurrent ankle episodes of "tilt".

Assessment of pressure distribution in the feet. Foot pressure measurements provide an assessment of foot and ankle function parameters during walking and other dynamic activities, as the foot and ankle provide the necessary support and mobility for weight transfer. Although the data on foot loads have been recognised as an important element in the assessment of patients with diabetes mellitus and peripheral neuropathy, information derived from the foot loads studied can also help to identify and treat disorders associated with various musculoskeletal and nervous system disorders [22].

Foot pressure measurement technology is increasingly used by podiatrists and surgeons alike in clinical practice and in a wide range of research. These tests provide important information to assess functional changes in the foot in the long term or to evaluate the effects of therapeutic interventions [27]. When assessing patients, atypical load distributions may reflect systemic or localized lower extremity pathology [22]. This measure can also be used to distinguish between normal and pathological gait, orthotic customization, to identify various foot deformities [20].

Various foot pathologies, deformities or injuries to the foot or ankle can change the pressure on a part of the foot and the trajectory of the centre of gravity, resulting in asymmetry between the loads on the feet. It is important to consider the individuality of each person, the type of gait, the shape of the foot and the problem at hand when analysing this data. It is this characteristic that makes foot pressure measurement data very useful in the investigation of various lower limb problems.

The problem statement is that ankle instability can adversely affect the whole biomechanics of body movement by altering the weight distribution in the feet. So, the aim of the study was to evaluate the associations between ankle instability and plantar pressure distribution. The objectives of the study: to provide a literature review of the main problems caused by the ankle joint instability; to assess the distribution of foot pressure in subjects during standing, walking and running; to review the relationship between ankle instability and weight distribution in the feet.

The study was carried out in accordance with the principles of professional ethics and without prejudice to the rights of the respondents, anonymity and confidentiality of the data obtained have been respected in order to avoid causing any harm confidentiality. The subjects with ankle instability or combined (functional and mechanical) ankle instability were invited and twenty individuals with at least 2 ankle joint sprain/strain or and experience instability in that joint during active, daily activities agreed to participate in the initial phase. According to the selection criteria, individuals suitable for the study were selected for the study:

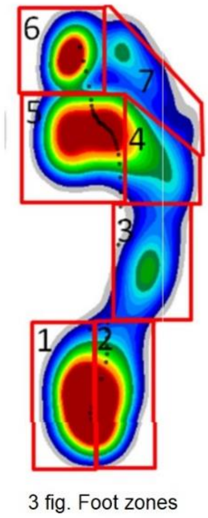
- Age: young, physically active;
- Functional Ankle Instability Questionnaire score ≥11 or a positive anterior drawer test for the ankle joint, assessment of mechanical stability;
- Not the first time walking and running on a treadmill;
- No history of fractures of the pelvis or other leg bones;
- No complaints of pelvic or knee pain and no history of ligament damage in these areas;
- Only one ankle joint has been affected and at least 2 times;
- Written informed consent to participate in the study.

Out of the 20 individuals, 4 were excluded from the study. Two of them have other leg bone fractures, and two had multiple fractures to both ankle joints, so these volunteers were excluded due to possible inaccuracy of the data. A total of 16 people took part in the study, of whom 10 men and 6 women. The age range was 18 to 27 years old, and the mean age was 21.4 years, standard deviation ± 2.13. The subjects signed a written personal consent form and were informed about the aim, methods and procedure of the study, were informed and assured of confidentiality and that the results of the study would be used only for scientific purposes.

The following research methods were used in the study:

- Identification of Functional Ankle Instability (IdFAI) Scale;
- Clinical anterior drawer test (CUT) for the ankle joint;
- Computerised plantography (SCHEIN PROFESSIONAL treadmill Zebris FDMTS70, Art. No. 032110022) (fig. 2). All SCHEINWORKS treadmills include integrated pressure measurement plates that allow pressure distribution when walking and running to be measured and analysed. The software calculates various gait parameters, which are depicted clearly in the software and report. he dimensions of the plate are 108,4 cm long, 47,4 cm wide cm, resolution 1,4 sensors/cm2 (Treadmill | SCHEINWORKS construction, 2021). The parameters analysed in the study are: pressure distribution (kPA), foot placement angle, and symmetry.
- Mathematical analysis to process the data. For the analysis of the data, mathematical statistical methods were used: arithmetic means (X), standard error of the arithmetic mean (SE), standard deviation (SD). All calculations were performed in Microsoft Office Excel 2018 Version 16.12.

2 fig. Dynamic gait analysis on the treadmill (zebris Medical GmbH: Dynamic gait analysis on the treadmill)

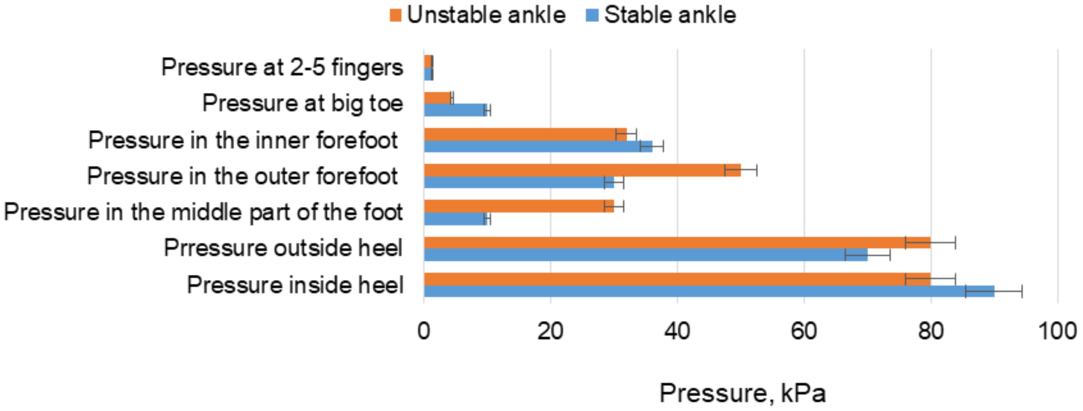


3 fig. Foot zones

In order to collect the pressure parameters in specific parts of the foot, the foot was divided into 7 zones: inside heel (1), outside heel (2), middle part of the foot (3), the outer forefoot (4), the inner forefoot (5), the big toe zone (6) and the zone of toes 2 to 5 (7). The data were analysed by calculating the mean pressure average pressure loads per 1cm2 (3 fig.)

Results of the study: Based on the results of the literature review, it was found that subjects with ankle instability had more lateral plantar pressure distribution and laterally deviated center of pressure. When plantar pressure distribution was evaluated and the results between injured and uninjured legs were compared, it was discovered that higher plantar pressure was experienced when standing, walking, and running in unstable ankles, which also had more laterally deviated ankles and less pressure distribution in the inner part of the foot. The biggest pressure differential was seen while jogging at the outer fore foot, where there was a difference of 70 (kPa) in the foot with ankle instability, 50 (kPa) in the center of the foot, and 50 (kPa) in the area of the big toe on the stable side. It was discovered during the course of the study that participants with combined ankle instability also had a greater difference in foot rotation degree in stance between the damaged and uninjured side, with the injured side's foot being put more inwards (difference – 4,7 degrees). Conclusions: The pressure in the foot is more evenly distributed in the outer part of the foot in subjects with ankle joint instability, according to the findings in literature. When the pressure distribution of the subjects' feet was measured and the results were contrasted between the injured and uninjured feet, it was discovered that subjects with ankle joint instability also experienced higher pressure in the outer part of the foot when standing, walking, and running.

During standing, the subjects' ankle-unstable leg was compared to their other leg, which had no damage to the external ligaments of the tibiofemoral joint (Fig. 6). The foot with ankle instability had a higher-pressure load on the outer part of the heel, mean 80 (kPA); standard deviation (SD) ±19.9. Similarly, in the midfoot, the mean pressure load was higher, 30 (kPa); SN ±19.1, and in the outer forefoot, the mean pressure distribution in the foot was 50 (kPa); SN ±19.1 (Figure 4). In the feet without damage to the external ligaments of the tibiofemoral joint, the highest-pressure distribution was at the inner part of the heel, with a mean of 90 (kPa); SN ±23.1, at the inner part of the forefoot, with a mean of 36 (kPa); SN ±9.6, and at the big toe area, with a mean of 10 (kPa); SN ±15.7. In the study, the pressure at the toe area of feet 2-5 was equally distributed, with a mean pressure of 1.3 (kPa) for both stable and unstable feet.



4 fig. Pressure distribution in subjects' feet while standing

The data showed that the distribution of pressure in the foot with ankle instability is asymmetrical and that in the foot with ankle instability the loaded zones were located on the outer part of the foot. It was at the midfoot and the outer forefoot that the greatest difference in pressure loads of 20 (kPa) was observed, and in the unstable foot, these zones were more heavily loaded. The stable foot had a stronger pressure concentration on the inner part of the foot, with 10 (kPa) more pressure on the inner heel, 4 (kPa) more pressure on the inner forefoot and 3.6 (kPa) more pressure on the big toe area.

During gait, foot pressure distributions were also compared between stable and unstable feet (Figure 5). A higher-pressure distribution in the ankle-unstable foot was found at the outer heel, with a mean of 200 (kPa); SN ±57.9, and in the midfoot with a mean of 100 (kPa); SN ±67.5. And the greatest difference in loads was found at the outer forefoot, with a mean of 210 (kPa) in the unstable half of the foot; SN ±74.7.

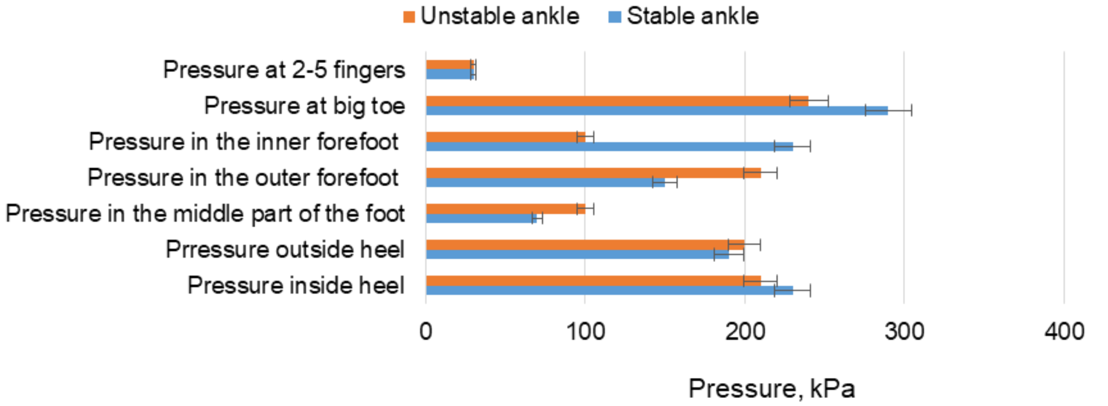


Fig. 5. Pressure distribution in subjects' feet during walking

On the stable and intact side, as well as during standing, the pressure concentration was higher on the inner part of the foot. The mean pressure at the inner heel was 230 (kPa); SN ±40.2, while the inter-subject pressure distribution at the inner forefoot was 230 (kPa); SN ±69.9. In the big toe area, the mean value was 290 (kPa); SN ±101.7. The study showed a uniform distribution of pressure in the toe area of feet 2 to 5, with the mean pressure of both stable and unstable feet was 30 (kPa). The highest-pressure distribution between the two subjects' feet remained at the outer forefoot, with a pressure difference of 60 (kPa) in the ankle unstable foot as the participants walked. The pressure difference was 30 (kPa) at the midfoot and only 10 (kPa) at the outer heel. In the intact foot, in contrast to the unstable side, the results of the pressure loads obtained during stance showed the highest difference at the big toe area of 50 (kPa). The difference in mean pressure at the inner forefoot on the stable side was 30 (kPa) more and the inner heel 20 (kPa) more.

The pressure distribution results from running show a similar difference between stable and unstable feet as the results from standing or walking (Figure 6). The pressure loads were also higher on the outer part of the foot in feet with ankle instability. The mean pressure loads at the outer heel were 190 (kPa); SN ±54 and at the midfoot at the outer longitudinal arch the mean was 160 (kPa); SN ±63.9. Similarly, in the more loaded forefoot, the mean pressure was 210 (kPa); SN ±61.7. In the tibiofemoral joint external ligament-sprained feet, the higher-pressure load is distributed on the inner heel, with a mean pressure of 253 (kPa); SN ±49,2, and in the inner forefoot with a mean pressure of 260 (kPa); SN ± 61.2. and in the big toe area 270 (kPa); SN ± 103. As in stance and gait during stance and gait, the mean pressure loads at toe zones 2-5 remained the same at 40 (kPa).

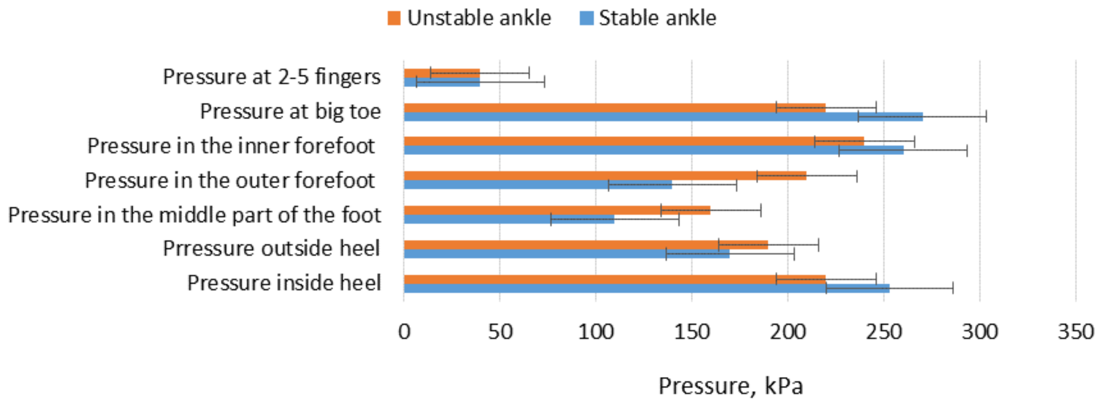


Fig. 6. Pressure distribution in subjects' feet during running

The greatest difference in the pressure distribution results obtained from the analysis of the running test was observed in the pressure at the outer forefoot, with the unstable foot being loaded 70 (kPa) more than the stable foot, the midfoot being loaded 50 (kPa) more, and the outer heel having a 20 (kPa) higher pressure distribution. On the stable side, 50 (kPa) more pressure load was applied to the big toe area, 33 (kPa) more to the inner heel area and 20 (kPa) more to the inner forefoot area. Various pressure, gait and symmetry parameters can be monitored in the computerised plantography report. The foot rotation degree during support was compared by analysing the data and based on the results obtained by other authors. The analysis of the data and the results of other studies were used to compare the angle of foot placement during weight-bearing and to look for a correlation between ankle joint instability and increased foot inversion [24].

The mean foot rotation degree (inversion) of the feet without tibiofemoral sprain is 5 degrees; SN ±4.54, while the mean foot rotation degree of the feet with ankle instability is 4 degrees; SN ±3.35. Difference between stable and unstable foot in the study is only 1 degree.

When subjects with combined and functional ankle instability were evaluated separately, the results showed that the difference in foot placement angle was greater for combined ankle instability compared to functional ankle instability. In the ankles with both functional and mechanical instability, the mean foot rotation degree was 3.8 degrees; SN ± 3.02, while in the opposite foot, the mean foot rotation degree was 8.5 degrees; SN ± 3.97. Subjects with functional instability of the ankle joint in the affected foot had a mean of 4 degrees of foot rotation; SN ± 3.62 and in the opposite foot 4.4 degrees; SN ± 4.13. The difference in foot rotation degree between the stable and unstable foot was found to be greater in subjects with combined ankle instability, with a difference of 4.7 degrees, and in those with functional instability, with a difference of 0.4 degrees. Therefore, based on the findings of this study and those of the authors of a similar study, it is likely that individuals with combined ankle instability will position the affected limb inward rather than outward in the stance phase, thus increasing the likelihood of recurrent ankle joint displacement [24].

The centre of gravity (CoG) is a measurement of neuromuscular control that occurs during posture and movement. SC movement has been described as the focal point of all external forces acting on the plantar surfaces of the foot and is used to determine balance control, foot functionality, deformity and injury characteristics, and treatment effectiveness [28]. In studies by other authors, this parameter is also mentioned as one of the elements indicating the association of ankle joint instability with pressure distribution in the feet.

Previous research [26] has found that in individuals with ankle instability, the movement of the centre of gravity was more pronounced at the outside of the foot throughout the stance phase, as was the distribution of pressure loads. The centre of gravity position of the ankle instability group was 2.9 mm lateral during the first 10% of the stance phase and 7.5 mm lateral - 50-60% of the stance phase.

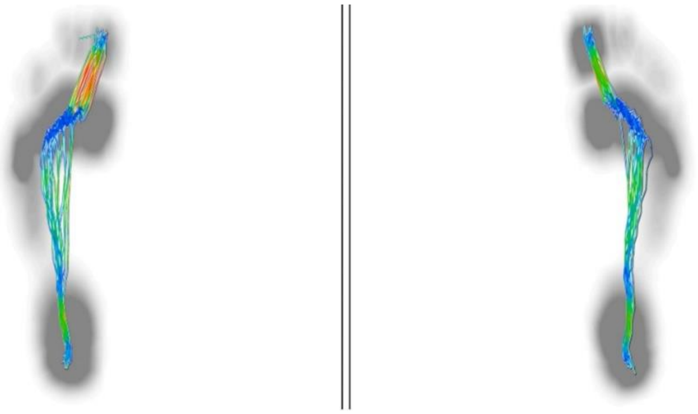


Fig. 7. Trajectory of the centre of gravity in feet at 20 sec. interval during gait.

In the study, the software did not provide measurements of the position of the centre of gravity trajectory, but instead provided a visual image (Figure 7) and some parameters that did not indicate asymmetry between the feet. However, the pressure distribution is closely related to the centre of gravity trajectory, and in order for the outer part of the foot to be more loaded, the line of movement of the centre of gravity has to move towards the outer part of the foot. In the visual assessment, the movement of this trajectory is observed at the outer part of the foot between the feet of the subjects with ankle instability. However, another interesting observation is not mentioned by any of the authors, is the location of the SC lines during several steps. Since the choice of recording the results was not one or several steps, but 20 sec. movement interval, it was observed that in feet with ankle instability, the location of the centre of gravity lines was spread over a larger foot surface compared to the intact foot. This explains the consequences of impaired neuromuscular control and proprioception in ankle instability

Conclusions: in subjects with ankle joint instability, the pressure in the foot is more distributed in the outer part of the foot; Assessing the pressure distribution of the subjects' feet and comparing the results between the injured and uninjured feet, it was found that higher pressure in the foot with ankle joint instability when standing, walking and running was also recorded at the outer part of the foot and less at the inner part of the foot, this changes the position of the center of mass and, in the long run, possible disturbances in the biomechanics of body movement and the pain they cause. Subjects with combined ankle instability will have a higher foot rotation degree difference between the two feet, with the affected side of the foot being placed more inwards. This has an effect on weight concentrating on the outer part of the foot and moving the centre of gravity more towards the outer part of the foot.

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