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Invited Review

Pedobarographic evaluations in physical medicine and rehabilitation practice

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ABSTRACT

The feet are complex structures that transmit loads transferred by other parts of the body to the ground and are involved in many static and dynamic activities, such as standing and walking. The contact area and pressure changes between the feet and the ground surface can be measured using pedobarographic devices. With pedobarographic examinations, it is possible to obtain a wide range of information needed to support clinical evaluation and diagnostic tests in physical medicine and rehabilitation practice. Foot structure and function, postural stability, lower extremity biomechanics, and gait analysis are among the areas that can be further investigated using pedobarography.

Keywords: Biomechanics, foot deformities, gait, postural balance.

Around the 1800s, the structural evaluations of the plantar surface began with the examination of bare footprints on various ground materials. Today, the assessment of the foot sole has reached an advanced stage with the use of pedobarographic analysis devices, which can analyze the plantar surface dynamically and in very small fields using numerous sensors. The foot is a highly complex structure that involves numerous muscles, joints, and soft tissues, all working in harmony with each other and has an integral role in both static and dynamic physical activities. The force interactions between the foot and the ground surface have inspired research on various aspects related to the foot in detail, such as foot anatomy and function, lower extremity alignment, biomechanical issues of the spine, and postural stability.

Pedobarographic examinations include two main types of analysis: static and dynamic studies. Static evaluations are conducted while the patient stands still on a platform (Figure 1). During static examination, the entire surface of the foot in contact with the ground is mapped by a device. Static analyses also demonstrate the amount of pressure generated on each unit area of the foot. This data is then used to obtain a pressure distribution map of the entire foot surface. The device software analyzes the pressures exerted on the plantar surface to determine the center of pressure (CoP) for each foot (Figure 2). Center of pressure does not only provide data on problems related to the foot but also informs about biomechanical changes affecting weight transfer and load-bearing processes in the body.

The highest pressure in the plantar region detected by a single sensor is referred to as "peak plantar pressure." Peak plantar pressure is one of the key parameters evaluated during examinations. Identification of the areas where the highest pressures occur on the plantar surface during loading provides guidance to clinicians about the need for

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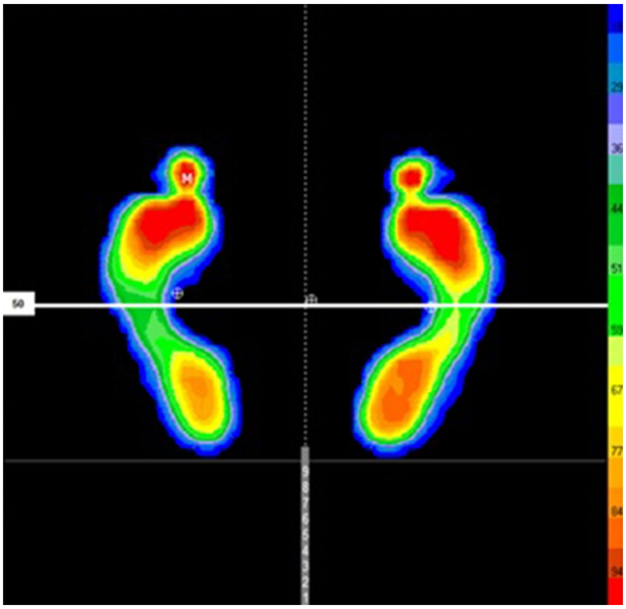

Figure 1. Static pedobarographic evaluation.

pressure-reducing insoles or modifications in the patient's orthoses in these areas.

The CoP progression can be determined by recording the displacement of the CoP on the foot sole during walking (Figure 2). Deviations in the expected CoP progression, either in the medial or lateral direction, provide information about foot anatomy or lower extremity alignment. In addition to the direction of CoP movements, the displacement velocity is also crucial. Slower CoP velocity during a specific phase of walking indicates slowed load transfer due to an existing pathology in that segment of the foot or a neurological disorder.

Despite being costly, long platforms that enable walking on them offer a number of advantages. Conflicting data reported in the literature regarding the pressure under the hallux has been attributed to the use of different platforms in patients with hallux valgus. It is believed that long platforms allow for the assessment of a more physiological pattern of gait.[1]

Additionally, pedobarographic analyses provide information about the distribution of body weight, including the proportion of weight borne on each foot and the amount of weight carried by different regions of each foot. By detecting existing asymmetries in weight distribution, these analyses can aid in early detection of conditions such as limb length discrepancy, pelvic asymmetry, lumbosacral dysfunction, and potential hip and knee joint pathologies.

The development of devices that can be worn inside shoes, such as wireless, pressure-sensitive insoles, has brought a new dimension to pedobarographic

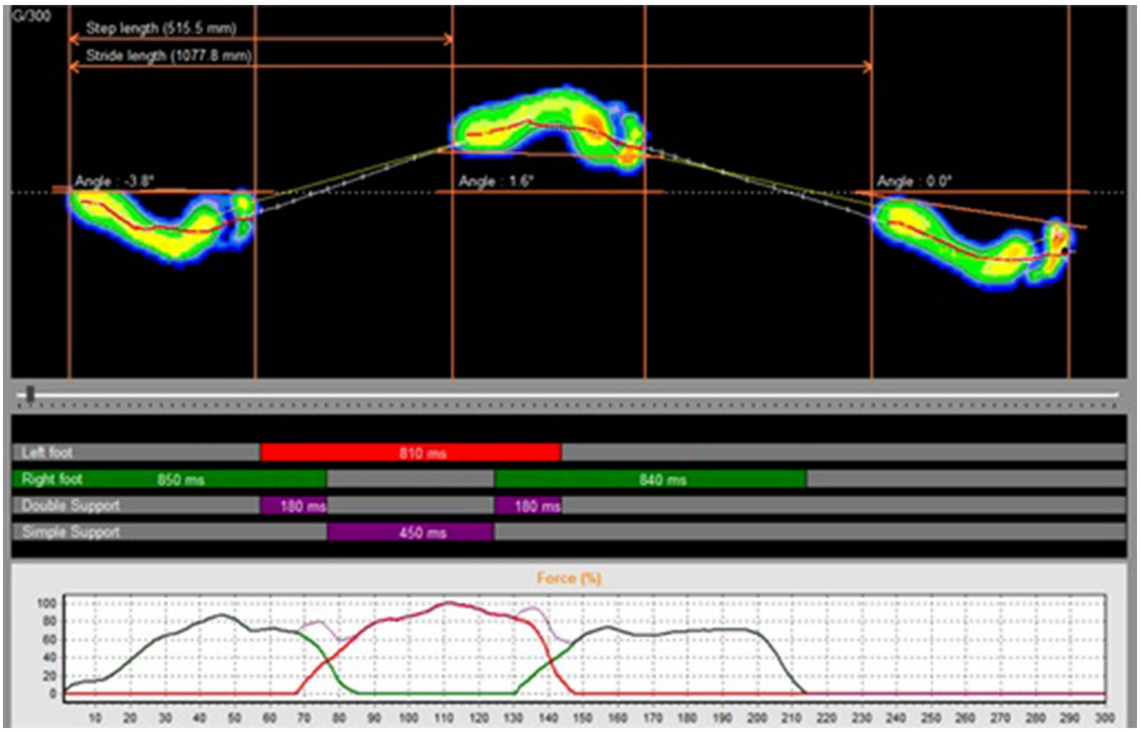

Figure 2. Dynamic pedobarographic evaluation.

analyses. By enabling pedobarographic analysis within natural walking performance, these devices facilitate the assessment of the suitability of shoe modifications and can reveal the gait line by evaluating the CoP trajectory through their software. It is widely accepted that frontal plane malalignment is compensated by the hindfoot in individuals with knee osteoarthritis. However, analyses conducted with insole-type devices have shown that the hindfoot fails to adequately compensate for frontal plane alignment problems of the knee joint.[2]

The development of thin, wearable analytical devices that can be placed inside shoes has been one of the most significant contributions to the evaluation of the effects of specific orthoses on various parts of the foot objectively and in real time. This enables demonstration of the real performance of orthoses that prevent postoperative weight bearing and the pressure changes they cause in other segments of the foot.[3] The Intrepid Dynamic Exoskeletal Orthosis used for critical limb injuries has been shown to reduce peak plantar pressure and increase the weight-bearing ratio on the healthy side.[4]

Many studies have demonstrated that apart from peak plantar pressure measurements in older adults, a single pedobarographic analysis conducted in children and adults is reliable and sufficient for evaluating plantar pressure distribution.[5] In pedobarographic analyses, assessment of plantar pressure distribution is essential for diagnosing and monitoring foot diseases, as well as for evaluation of postural stability, biomechanics of the foot and lower extremity, analysis of diabetic foot risk, neurological disorders, sports injuries, gait analysis, and orthoses and shoe modifications.

EVALUATION OF PLANTAR PRESSURE DISTRIBUTION

The structural and mechanical properties of the plantar fascia and intrinsic foot muscles are important factors that determine plantar pressure distribution. This is because these two structures play a key role in the stabilization of the foot arch.[6] Periodically evaluating plantar pressure distribution during childhood allows for monitoring the development of the medial arch, the presence of structural foot problems, and how they progress with growth. When examining pedobarographic data, it appears that the age of 14 years is a critical age in terms of changes in plantar pressure distribution, likely due to the impact of growth and increased body mass index during adolescence.[7]

Plantar pressure distributions are influenced by various factors, such as racial characteristics, foot type, and anthropometric features. Both barefoot and in-shoe pressure measurements performed in healthy individuals provide valuable data for the development of properly fitting footwear. These examinations also provide specific pressure patterns associated with different activities, such as walking and running.[8]

Metatarsalgia is a general term used to describe pain in the metatarsal region of the foot. Hallux valgus is one of the leading pathologies associated with pain in this area. However, not all patients with hallux valgus experience metatarsalgia. Very high plantar pressure values have been demonstrated in patients with hallux valgus and metatarsalgia. It was reported that the average pressure values measured under the big toe may be considered an indicator of the development of metatarsalgia.[9]

Studies have shown that pressure-reducing shoes and orthoses used in rearfoot pathologies similarly reduce rearfoot pressure by around 50%. However, as a limitation, both devices cause a significant increase in pressure in the neighboring midfoot zone. Therefore, care should be exercised when using these devices in patients with problems such as midfoot injury.[10]

PLANTAR CONTACT AREA ASSESSMENT

Many congenital or acquired structural foot problems cause changes in the plantar area that comes into contact with the ground. Among the structural problems of the foot, pes planus leads to an increase in the plantar contact area while pes cavus causes a decrease in the contact area. Apart from structural foot problems, a number of conditions, such as lower limb shortness, pelvic and spinal issues, neurological diseases, and spasticity, can lead to asymmetric lower limb loading, resulting in changes in the plantar contact area (Figure 3). It has been shown that up to the age of 13, both sexes have similar plantar contact areas. However, around the age of 14, a significant divergence occurs in the plantar contact area between girls and boys.[7]

ASSESSMENT OF LOWER EXTREMITY BIOMECHANICS

Pedobarographic methods have provided an opportunity to understand the mechanical and functional differences caused by different foot types during stance or walking. These assessments offer valuable insights into lower extremity biomechanics.

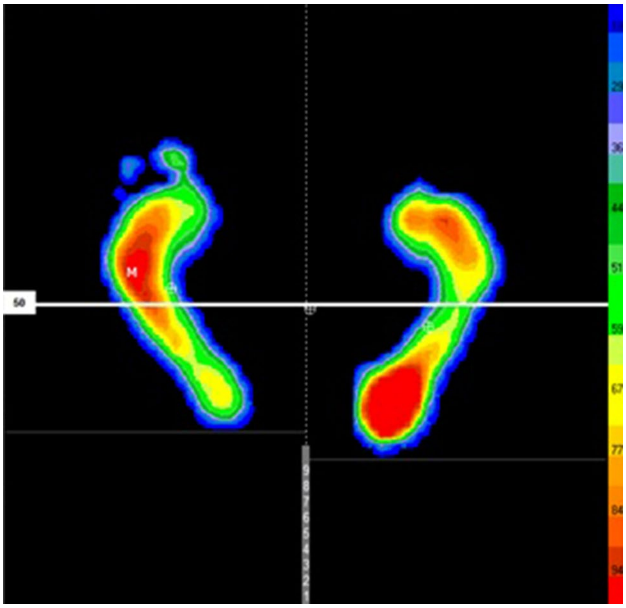

Figure 3. Decreased heel contact and impaired plantar pressure distribution in a patient with a short left leg.

The frontal plane biomechanics of the knee joint can be evaluated by analyzing alterations in plantar pressure. Early detection of frontal plane pathologies allows for the elimination of alignment problems, particularly those affecting the medial compartment, by correcting foot posture through interventions such as insoles, foot wedges, and exercise.

In patients with unilateral osteoarthritis, it has been shown that plantar pressure is lateralized both on the affected and unaffected sides, and this lateralization is correlated with radiological stages of osteoarthritis.[11] Through dynamic pedobarographic evaluation, a correlation has been demonstrated between the severity of varus thrust and radiological stages in patients with knee osteoarthritis.[12] In older adults, planus foot morphology was demonstrated to be associated with knee pain and medial tibiofemoral joint damage.[13]

In individuals with knee osteoarthritis, frontal plane alignment problems, such as valgus or varus, affect the ankle and foot. In the presence of varus in the knee, compensation in the hindfoot occurs through eversion, while in the case of valgus, compensation involves inversion. Postoperative ankle pain is frequently observed, particularly in patients with excessive knee varus or valgus. To prevent the occurrence of these problems after total knee arthroplasty, it is recommended to conduct preoperative pedobarographic analysis to examine the condition of the foot and ankle. The same recommendation also applies to individuals who will receive medial or lateral arch-supporting insoles due to knee osteoarthritis.[2]

Pedobarographic examinations have made significant contributions to understanding the biomechanical changes caused by partial foot amputations and their effects on the gait cycle.[14] In patients with total knee arthroplasty, pedobarographic analyses enable objective assessment of abnormal movement patterns. The lack of definitive objective methods for diagnosing instability in these patients can lead to challenges in clinical diagnosis. However, with pedobarographic examination, it is possible to reveal inconsistent weight-bearing in patients with instability.[15]

Pedobarographic systems also enable the examination of sex-related differences in plantar pressure distributions. In females, it has been shown that during standing and walking activities, plantar pressures are greater in the hallux, toes, forefoot, and medial regions of the foot compared to males.[16]

GAIT ANALYSIS

Pedobarographic devices, other than small platforms that allow for only static evaluation, offer the opportunity to examine parameters related to gait because they can record data during consecutive steps. Parameters such as walking speed, stride length, cadence, and single- and double-limb support times can be evaluated (Figure 2). Unlike three-dimensional motion analysis devices used in gait analysis, changes in plantar pressure and surface area throughout all phases of walking can be recorded during pedobarographic gait analysis. This is valuable since it enables demonstration of the real biomechanical effects caused by foot problems, as well as orthoses prescribed for the protection of the medial knee joint, shoe modifications, foot wedges, and other applications.

The foot progression angle is a key parameter that undergoes changes in various orthopedic and neurological conditions, making it an important tool for evaluating the effectiveness of rehabilitation programs. This angle, which is formed between the long axis of the foot from the calcaneus to the second metatarsal and the line of progression of gait, is generally calculated through kinematic analyses with the help of sensors placed on the foot.[17] However, with the introduction of pedobarography, which allows dynamic gait analysis, it has become possible to calculate the foot progression angle using the CoP progression lines.[18]

In patients with cervical myelopathy, as the degree of stenosis increases, walking speed and stride length decrease, while the toe-out angle increases.[19] The angle between the foot's long axis and the line of progression of gait is referred to as the toe angle. Using the same method, it has been determined that increased severity of low back pain is associated with a decrease in stride length, cadence, and walking speed in patients with lumbar disc herniation.[20]

ASSESSMENT OF POSTURAL STABILITY

By recording instantaneous CoP displacements from static evaluations over a certain period, it is possible to obtain information about the body's postural balance. Center of pressure oscillations can be evaluated both in the anteroposterior and mediolateral directions. This helps determine whether postural instability is specific to a particular direction or due to a total balance disorder. In a study conducted with patients with ankylosing spondylitis, we found significant postural instability prominent in the anterior-posterior direction.[21]

The examination of abnormalities of plantar pressure distribution caused by spinal deformities, particularly scoliosis, is another area where pedobarographic methods have been used in recent years. The correlation between coronal balance and plantar pressure distribution has been demonstrated in patients with idiopathic adolescent scoliosis.[22]

STRUCTURAL FOOT DISORDERS

Physical examination, radiological evaluation, and measurements on X-rays are crucial for the diagnosis and follow-up of structural abnormalities of the foot. Pedobarographic examinations provide objective quantitative data through analysis of the foot's contact area and plantar pressure distribution. Radiological measurements provide detailed information about the static alignment of bones. Pedobarographic examinations, on the other hand, offer the advantage of informing about extremity dynamics throughout the gait cycle. The reproducibility of these examinations allows for objective follow-up of the outcomes of surgical interventions, orthoses, footwear modifications, and exercise programs, in addition to the initial diagnosis.

Pes planus is characterized by the collapse of the medial longitudinal arch of the foot during weight-bearing and walking (Figure 4). In patients with pes planus, abnormal distribution of the load on the foot needs to be corrected. Medial arch-supporting insoles used in these patients have been shown to increase the weight-bearing capacity of the contact surface in the midfoot region, resulting in reduced pressure on the forefoot and rearfoot. Demonstration of the regional pressure changes caused by various insoles on the plantar contact area is important for the development of orthotic devices, which are primarily designed to redistribute plantar pressure.[23] It has been demonstrated that measurements of mediolateral pressure and surface area ratios on both single-leg and double-leg standing positions are useful in the diagnosis of pediatric flatfoot.[24]

Pes cavus, which can occur due to various etiological reasons, is characterized by a decrease in the total foot contact area on pedobarographic examination (Figure 5). In these patients, it has been shown that plantar pressures increase in the forefoot, midfoot, and rearfoot regions, except for the fifth metatarsal area.[25] The CoP shifts towards the medial side of the foot in pes planus, while in pes cavus, it shifts towards the lateral side of the foot.[26]

Metatarsus adductus is a relatively common foot deformity that can cause pain around the fourth and fifth metatarsocuboid joints and the dorsal part of the foot in adulthood. Pedobarographic examinations have revealed that during walking, patients with metatarsus adductus tend to load more weight on the lateral column of the forefoot, midfoot, and rearfoot. This finding led to a better understanding of the

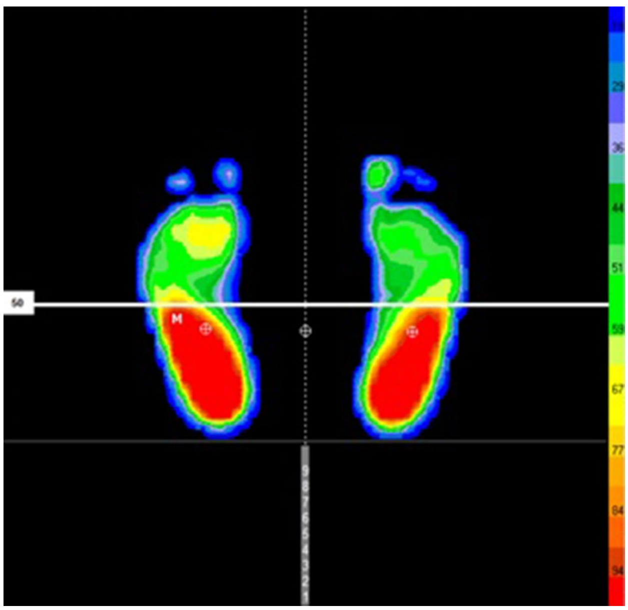

Figure 4. Static pedobarographic examination in pes planus.

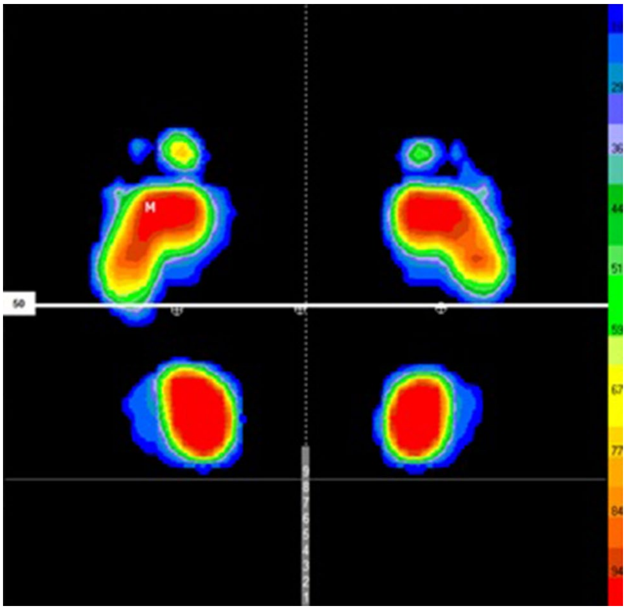

Figure 5. Static pedobarographic examination in pes cavus.

underlying cause of clinical problems involving the lateral aspect of the foot in the later stages.[27]

Inflammatory arthritides, such as rheumatoid arthritis, are conditions that are commonly associated with foot deformities. The primary goal of using orthoses and shoe modifications in rheumatologic diseases is to ensure the redistribution of plantar pressure and restore the foot's physiological load distribution. Rather than standard insoles, custom-made devices that are based on analysis of the patient's plantar pressure distribution help optimize the outcomes of corrective procedures. Rheumatologic problems often affect the forefoot. Patients initially exhibiting greater plantar pressure in the forefoot have been shown to experience more significant reductions in plantar pressure after using orthoses. Pedobarographic studies have demonstrated that alleviation of pain and improvement in quality of life observed after using orthoses in patients with rheumatoid arthritis cannot be solely explained by the reduction in forefoot pressure.[28]

Static and dynamic plantar examination data have been reported in acromegaly, a condition characterized by chronic bone and soft tissue overgrowth. It has been found that acromegalic patients exhibit increased peak plantar pressure in the midfoot and reduced peak medial heel pressure.[29] In individuals with abnormal plantar force and contact area, hypertrophy of the plantar fascia and intrinsic foot muscles has been detected through pedobarographic analyses.[30]

SPORTS INJURIES

It is known that long-term cumulative stress can lead to stress fractures in the foot bones. Identifying areas of excessive stress and asymmetric loading through assessment of plantar pressure distribution is important for preventing stress fractures. In young soccer players, asymmetric foot pressure distribution has been observed, with excessive pressure on the hallux, medial rearfoot, and the head of the fifth metatarsal bone.[31]

In military recruits, pedobarographic examinations conducted during barefoot running were performed to investigate the factors that increase the risk of fractures.[32] The study has shown that as the ratio of the midfoot's ground contact area decreases during the stance phase, the risk of stress fracture in the second metatarsal increases. In individuals with second metatarsal fractures, another influential factor is the decreased angle of foot abduction. These factors have been associated with a high arch, where the forefoot is in more adduction compared to the rearfoot and the midfoot's contact area is reduced. In the same study, it has been demonstrated that individuals with delayed peak plantar pressure in the second metatarsal during the push-off phase have an increased risk for third metatarsal fractures. The third metatarsal is a critical structure during the push-off phase of running.[32]

In children with Sever's disease, it has been shown that plantar pressure in the heel region is significantly greater compared to healthy controls.[33] McNab et al.[34] has demonstrated that older individuals with equinus in the ankle and a higher body mass index have increased plantar pressures in the forefoot and midfoot, making them more susceptible to related risks.

In individuals with anterior cruciate ligament injury, it was shown that the plantar pressure in the midfoot was higher, and the pressure in the rearfoot was lower compared to controls. However, postoperative evaluations in these patients indicated that the plantar pressure was comparable to that of controls.[35]

Pedobarographic examinations enable the assessment of extremity biomechanics and improvement of functional status following orthopedic surgery. Postoperative pedobarography was used for follow-up in patients with Lisfranc fractures in whom structural problems can persist despite optimal treatment. Despite long-term management, longer midfoot contact time and decreased maximum force, contact area, and peak pressure were detected in the fractured side compared to the uninjured side.[36]

NEUROLOGICAL DISORDERS

Any neurological disorder that causes dynamic imbalance in the lower extremity muscles can lead to problems in walking and balance due to impaired segmental control of foot and ankle movements. Loss of foot function and foot deformities caused by hemiplegia result in significant postural instability and mobility problems in affected patients. The ability to measure dynamic foot characteristics in a repeatable manner makes pedobarographic assessments important in the development and follow-up of rehabilitation programs for hemiplegic patients (Figure 6). Repeated measurements from hemiplegic patients have shown the reliability of pedobarographic data.[37]

Cerebral palsy, a clinical condition where foot and ankle problems along with walking difficulties represent major problems, is one of the areas where pedobarographic assessments can be most effectively used. Although common problems like pes planovalgus are traditionally evaluated through physical examination and radiological measurements, it is known that pedobarographic analyses provide valuable data in these conditions.[38] In cerebral palsy, where ankle plantar flexors are dominant, a pedobarographic gait analysis typically shows initial contact of the forefoot with the ground, disturbed CoP progression, and the heel mostly making the last contact with the ground with low pressure. Some dynamic foot pressure indices generated using plantar pressure distributions have been shown to be very useful in monitoring patients with spastic equinus.[39]

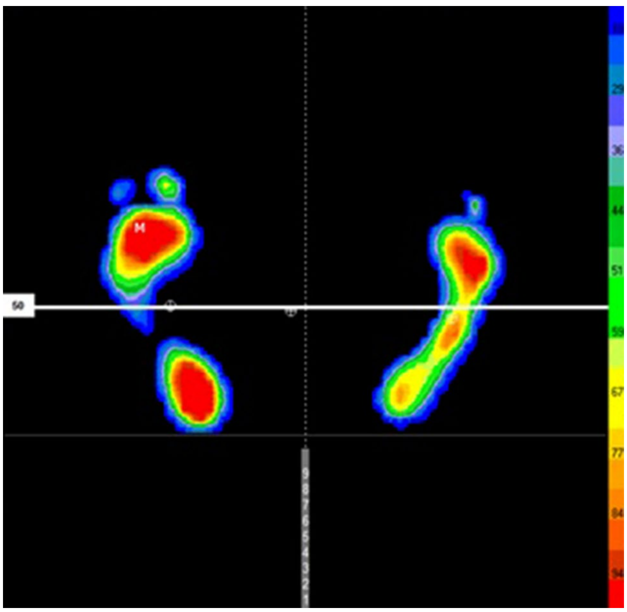

Figure 6. Static pedobarographic examination in a patient with right hemiplegia.

In healthy individuals, the activity of the plantar flexor muscles ensures the adaptation of the foot to the ground and creates a synchronized gait pattern. Studies in individuals with multiple sclerosis have shown that there is a problem in the transfer of load to the forefoot after a heel strike. This highlights the importance of gait training in multiple sclerosis rehabilitation.[40]

DIABETIC FOOT

Neuropathy is one of the most common complications of diabetes. Neuropathy leads to decreased protective sensation, plantar pressure abnormalities, development of deformities, and increased risk of mechanical trauma. Pedobarographic assessments have a high diagnostic value in predicting, preventing, and monitoring diabetic foot, which represents a significant clinical problem in diabetic patients.

Identification of areas with high plantar pressure provides important warning data for using pressure-reducing measures and ensuring careful foot care, particularly in those regions (Figure 7). Improper foot orthoses and shoe applications that do not provide adequate support to the relevant areas have been reported to increase the risk of ulcer formation. In patients with diabetic neuropathy, it has been demonstrated that impaired sensation of touch leads to increased contact with the ground in certain foot regions as well as reduced loading in other areas. This increases the risk of ulcer formation in the plantar

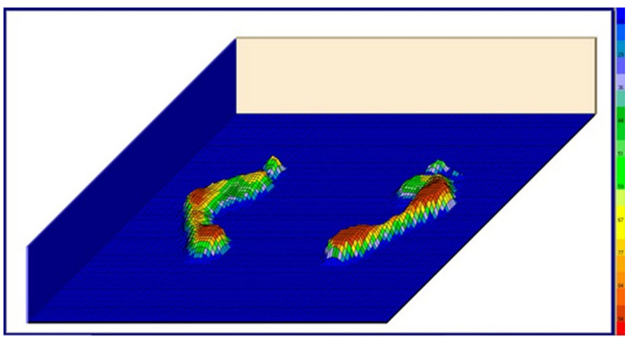

Figure 7. Three-dimensional analysis in a diabetic patient; the red areas show the regions with the highest plantar pressure.

regions exposed to high pressure and also results in postural instability and altered gait patterns.[41]

In patients with diabetic neuropathy, it has been shown that the severity of neuropathy is associated with plantar pressure distribution. Peak plantar pressure has been reported to be higher in the heel, medial forefoot, and midfoot in patients with severe neuropathy.[42] In addition to disease duration, glycemic control, and the severity of neuropathy, plantar pressure distribution is also considered an important risk factor for ulcer development in diabetic patients. In particular, peak plantar pressure in the forefoot is regarded as an important indicator, and a peak pressure value of 350 kPa has been suggested as a cut-off value for high risk of ulceration.[43] In another study, it was demonstrated that in patients with long-term diabetes, there is a decrease in pressure in the hallux region while there is an increase in pressure in the metatarsal and heel regions. The gradual decrease in pressure in the hallux region over time was reported to increase the likelihood of diabetic foot ulcer formation.[44]

In conclusion, pedobarographic analyses provide objective information not only about the foot structure and function but also about gait analysis, postural stability, and lower extremity biomechanics. Evaluating this data in the patients requiring pedobarographic assessment provides guidance for diagnosis, as well as for developing rehabilitation protocols and monitoring treatment outcomes. Therefore, in the practice of physical medicine and rehabilitation, the use of pedobarographic analyses should be considered when there is a need for supportive objective information alongside clinical evaluation and other examination methods.

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REFERENCES

1. Hofmann UK, Götze M, Wiesenreiter K, Müller O, Wünschel M, Mittag F. Transfer of plantar pressure from the medial to the central forefoot in patients with hallux valgus. BMC Musculoskelet Disord 2019;20:149. doi: 10.1186/s12891-019-2531-2.
2. Rühling M, Kirschbaum S, Perka C, Graef F. Functional gait analysis reveals insufficient hindfoot compensation for varus and valgus osteoarthritis of the knee. Int Orthop 2023;47:1233-42. doi: 10.1007/s00264-023-05738-5.
3. Ehrnthaller C, Rellensmann K, Baumbach SF, Wuehr M, Schniepp R, Saller MM, et al. Pedobarographic evaluation of five commonly used orthoses for the lower extremity. Arch Orthop Trauma Surg 2023;143:4249-56. doi: 10.1007/s00402-022-04729-2.
4. Stewart J, Djafar T, Miltenberger R, Kingsbury T, Wyatt M. Plantar pressure changes with use of an intrepid dynamic exoskeletal orthosis. J Prosthet Orthot 2019;32. doi: 10.1097/JPO.0000000000000281.
5. Franco PS, Moro CF, Figueiredo MM, Azevedo RR, Ceccon FG, Carpes FP. Within and between-days repeatability and variability of plantar pressure measurement during walking in children, adults and older adults. Adv Rheumatol 2018;58:15. doi: 10.1186/s42358-018-0014-z.
6. McKeon PO, Hertel J, Bramble D, Davis I. The foot core system: A new paradigm for understanding intrinsic foot muscle function. Br J Sports Med 2015;49:290. doi: 10.1136/bjsports-2013-092690.
7. Demirbüken İ, Özgül B, Timurtaş E, Yurdalan SU, Çekin MD, Polat MG. Gender and age impact on plantar pressure distribution in early adolescence. Acta Orthop Traumatol Turc 2019;53:215-20. doi: 10.1016/j.aott.2019.01.006.
8. Mei Q, Gu Y, Xiang L, Yu P, Gao Z, Shim V, et al. Foot shape and plantar pressure relationships in shod and barefoot populations. Biomech Model Mechanobiol 2020;19:1211-24. doi: 10.1007/s10237-019-01255-w.
9. Verdu Roman C, Martinez Gimenez E, Bustamante Suarez de Puga D, Mas Martinez J, Morales Santias M, Sanz-Reig J. Hallux valgus with and without metatarsalgia in women: A matched-cohort study of plantar pressure measurements. Indian J Orthop 2021;55(Suppl 2):436-44. doi: 10.1007/s43465-021-00416-3.
10. Mazur F, Swoboda B, Carl HD, Lutter C, Engelhardt M, Hoppe MW, et al. Plantar pressure changes in hindfoot relief devices of different designs. J Exp Orthop 2019;6:7. doi: 10.1186/s40634-019-0173-9.
11. He YJ, Zheng XL, Wang DF, Mu ZZ, Li GY, Fang ZZ, et al. Static and dynamic plantar pressure distribution in 94 patients with different stages of unilateral knee osteoarthritis using the Footscan® platform system: An observational study. Med Sci Monit 2023;29:e938485. doi: 10.12659/MSM.938485.
12. Ohi H, Iijima H, Fukutani N, Aoyama T, Kaneda E, Ohi K, et al. Varus thrust visualized during gait was associated with inverted foot in patients with knee osteoarthritis: An exploratory study. Gait Posture 2018;61:269-75. doi: 10.1016/j.gaitpost.2018.01.020.
13. Gross KD, Felson DT, Niu J, Hunter DJ, Guermazi A, Roemer FW, et al. Association of flat feet with knee pain and cartilage damage in older adults. Arthritis Care Res (Hoboken) 2011;63:937-44. doi: 10.1002/acr.20431.

14. de Oliveira FCL, Williamson S, Ardern CL, Fagher K, Heron N, Janse van Rensburg DCC, et al. Association between the level of partial foot amputation and gait: A scoping review with implications for the minimum impairment criteria for wheelchair tennis. Br J Sports Med 2022:bjsports-2022-105650. doi: 10.1136/bjsports-2022-105650.
15. Sehgal A, Burnett R, Howie CR, Simpson AHRW, Hamilton DF. The use of pedobarographic analysis to evaluate movement patterns in unstable total knee arthroplasty: A proof of concept study. Knee 2021;29:110-5. doi: 10.1016/j.knee.2021.01.010.
16. Yamamoto T, Hoshino Y, Kanzaki N, Nukuto K, Yamashita T, Ibaraki K, et al. Plantar pressure sensors indicate women to have a significantly higher peak pressure on the hallux, toes, forefoot, and medial of the foot compared to men. J Foot Ankle Res 2020;13:40. doi: 10.1186/s13047-020-00410-2.
17. Schelhaas R, Hajibozorgi M, Hortobágyi T, Hijmans JM, Greve C. Conservative interventions to improve foot progression angle and clinical measures in orthopedic and neurological patients - A systematic review and meta-analysis. J Biomech 2022;130:110831. doi: 10.1016/j.jbiomech.2021.110831.
18. Caderby T, Begue J, Dalleau G, Peyrot N. Measuring foot progression angle during walking using force-plate data. Applied Mechanics 2022;3:174-81. doi: 10.3390/applmech3010013.
19. Nagai T, Takahashi Y, Endo K, Ikegami R, Ueno R, Yamamoto K. Analysis of spastic gait in cervical myelopathy: Linking compression ratio to spatiotemporal and pedobarographic parameters. Gait Posture 2018;59:152-6. doi: 10.1016/j.gaitpost.2017.10.013.
20. Bonab M, Colak TK, Toktas ZO, Konya D. Assessment of spatiotemporal gait parameters in patients with lumbar disc herniation and patients with chronic mechanical low back pain. Turk Neurosurg 2020;30:277-84. doi: 10.5137/1019-5149.JTN.27499-19.2.
21. Mesci E, Mesci N. The relationship of multifidus and gastrocnemius muscle thickness with postural stability in patients with ankylosing spondylitis. Turk J Phys Med Rehabil 2023;69:222-9. doi: 10.5606/tftrd.2023.11990.
22. Ma Q, Lin H, Wang L, Zhao L, Chen M, Wang S, et al. Correlation between spinal coronal balance and static baropodometry in children with adolescent idiopathic scoliosis. Gait Posture 2020;75:93-7. doi: 10.1016/j.gaitpost.2019.10.003.
23. Cho YJ, Lee DH, Kang HW, Kim DY, Lee DO, Lee DY. Pressure properties of three different types of prefabricated insoles related to plantar pressure in asymptomatic men. Clin Orthop Surg 2022;14:622-30. doi: 10.4055/cios20280.
24. Pallamar M, Bock P, Kranzl A, Fruehwald-Pallamar J, Farr S, Ganger R. Does the way of weight-bearing matter? Single-leg and both-leg standing radiographic and pedobarographic differences in pediatric flatfoot. Gait Posture 2022;93:135-41. doi: 10.1016/j.gaitpost.2022.01.009.
25. Fernández-Seguín LM, Diaz Mancha JA, Sánchez Rodríguez R, Escamilla Martínez E, Gómez Martín B, Ramos Ortega J. Comparison of plantar pressures and contact area between normal and cavus foot. Gait Posture 2014;39:789-92. doi: 10.1016/j.gaitpost.2013.10.018.
26. Buldt AK, Allan JJ, Landorf KB, Menz HB. The relationship between foot posture and plantar pressure during walking in adults: A systematic review. Gait Posture 2018;62:56-67. doi: 10.1016/j.gaitpost.2018.02.026.
27. Fishco WD, Ellis MB, Cornwall MW. Influence of a metatarsus adductus foot type on plantar pressures during walking in adults using a pedobarograph. J Foot Ankle Surg 2015;54:449-53. doi: 10.1053/j.jfas.2014.11.007.
28. Tenten-Diepenmaat M, Dekker J, Twisk JWR, Huijbrechts E, Roorda LD, van der Leeden M. Outcomes and potential mechanism of a protocol to optimize foot orthoses in patients with rheumatoid arthritis. BMC Musculoskelet Disord 2020;21:348. doi: 10.1186/s12891-020-03364-5.
29. Sendur SN, Oguz S, Dagdelen S, Erbas T. Assessment of static and dynamic plantar data of patients with acromegaly. Pituitary 2019;22:373-80. doi: 10.1007/s11102-019-00964-w.
30. Taş S, Çetin A. An investigation of the relationship between plantar pressure distribution and the morphologic and mechanic properties of the intrinsic foot muscles and plantar fascia. Gait Posture 2019;72:217-21. doi: 10.1016/j.gaitpost.2019.06.021.
31. Azevedo RR, da Rocha ES, Franco PS, Carpes FP. Plantar pressure asymmetry and risk of stress injuries in the foot of young soccer players. Phys Ther Sport 2017;24:39-43. doi: 10.1016/j.ptsp.2016.10.001.
32. Dixon S, Nunns M, House C, Rice H, Mostazir M, Stiles V, et al. Prospective study of biomechanical risk factors for second and third metatarsal stress fractures in military recruits. J Sci Med Sport 2019;22:135-9. doi: 10.1016/j.jsams.2018.06.015.
33. Rodríguez-Sanz D, Becerro-de-Bengoa-Vallejo R, López-López D, Calvo-Lobo C, Martínez-Jiménez EM, Perez-Boal E, et al. Slow velocity of the center of pressure and high heel pressures may increase the risk of Sever's disease: A case-control study. BMC Pediatr 2018;18:357. doi: 10.1186/s12887-018-1318-1.
34. McNab B, Sadler S, Lanting S, Chuter V. The relationship between foot and ankle joint flexibility measures and barefoot plantar pressures in healthy older adults: A cross-sectional study. BMC Musculoskelet Disord 2022;23:729. doi: 10.1186/s12891-022-05618-w.
35. Çetin E, Deveci MA, Songür M, Özer H, Turanli S. Evaluation of plantar pressure distributions in patients with anteriorcruciate ligament deficiency: Preoperative and postoperative changes. Turk J Med Sci 2017;47:587-91. doi: 10.3906/sag-1601-146.
36. Eceviz E, Çevik HB, Öztürk O, Özen T, Çolak TK, Çolak İ, et al. Pedobarographic, clinic, and radiologic evaluation after surgically treated Lisfranc injury. J Invest Surg 2021;34:1191-7. doi: 10.1080/08941939.2020.1790700.
37. Rogers A, Morrison SC, Gorst T, Paton J, Freeman J, Marsden J, et al. Repeatability of plantar pressure assessment during barefoot walking in people with stroke. J Foot Ankle Res 2020;13:39. doi: 10.1186/s13047-020-00407-x.
38. Look N, Autruong P, Pan Z, Chang FM, Carollo JJ. Radiographic and plantar pressure assessment of pes planovalgus severity in children with cerebral palsy. Clin Biomech (Bristol, Avon) 2021;85:105364. doi: 10.1016/j.clinbiomech.2021.105364.

39. Bennett D, Walsh M, O'Sullivan R, Gallagher J, O'Brien T, Newman CJ. Use of a dynamic foot pressure index to monitor the effects of treatment for equinus gait in children with cerebral palsy. J Pediatr Orthop 2007;27:288-94. doi: 10.1097/BPO.0b013e3180342899.
40. Keklicek H, Cetin B, Salci Y, Balkan AF, Altinkaynak U, Armutlu K. Investigating the dynamic plantar pressure distribution and loading pattern in subjects with multiple sclerosis. Mult Scler Relat Disord 2018;20:186-91. doi: 10.1016/j.msard.2018.01.023.
41. Jorgetto JV, Oggiam DS, Gamba MA, Kusahara DM. Factors associated with changes in plantar pressure of people with peripheral diabetic neuropathy. J Diabetes Metab Disord 2022;21:1577-89. doi: 10.1007/s40200-022-01104-1.
42. Abri H, Aalaa M, Sanjari M, Amini MR, Mohajeri-Tehrani MR, Larijani B. Plantar pressure distribution in diverse stages of diabetic neuropathy. J Diabetes Metab Disord 2019;18:33-9. doi: 10.1007/s40200-019-00387-1.
43. Fawzy OA, Arafa AI, El Wakeel MA, Abdul Kareem SH. Plantar pressure as a risk assessment tool for diabetic foot ulceration in Egyptian patients with diabetes. Clin Med Insights Endocrinol Diabetes 2014;7:31-9. doi: 10.4137/CMED.S17088.
44. Xu L, Zeng H, Zhao J, Zhao J, Yin J, Chen H, et al. Index of plantar pressure alters with prolonged diabetes duration. Diabetes Ther 2019;10:2139-52. doi: 10.1007/s13300-019-00697-w.