Jacek LORKOWSKI[1,2]
Oliwia GRZEGOROWSKA[2]

Is pedobarography applicable only in orthopaedics?

Czy pedobarografia znajduje zastosowanie jedynie w ortopedii?

[1]Department of Orthopaedics and Traumatology, Central Clinical Hospital of Ministry of Interior, Warsaw.
Head of the Clinic:
prof. Ireneusz Kotela M.D., Ph.D.
Woloska 137 St
02-507 Warsaw

[2]Rehabilitation Centre „Health", Cracow.
Head of the Centre:
Tadeusz Mazur M.D., Ph.D.
Gertrudy 28 St, Cracow

Pedobarographic examination is a non-invasive and cheap diagnostic method of the locomotor system, which enables an assessment of plantar pressures distribution during stance and gait. It applies to both children and adults not only in the orthopaedics. Also, it facilitates an assessment of locomotor system pathologies in various systemic and somatic disorders. The course of the disease and the effectiveness regarding musculoskeletal system can be monitored by using the pedobarographic examination. The article below presents the possibilities of pedobarography application in pathologies primary independent from feet disorders and many other, both physiological and pathological, issues concerning the motor system primary independent from the ankle joint and foot pathologies. In our opinion pedobarography should be used more often and together with other diagnostic methods, should normally supplement the process of diagnostics.

Pedobarografia jest nieinwazyjnym i tanim badaniem diagnostycznym układu ruchu, które umożliwia ocenę rozkładu ciśnień podstopnych podczas stania i chodu. Może być stosowane u dzieci i dorosłych, nie tylko w ortopedii. Co więcej, umożliwia ocenę patologii układu ruchu w różnych chorobach systemowych i somatycznych, z jego pomocą można monitorować przebieg oraz oceniać skuteczność leczenia schorzeń przebiegających z zajęciem układu mięśniowo-szkieletowego. Poniższy artykuł przedstawia szerokie możliwości wykorzystania badania pedobarograficznego w chorobach pierwotnie niezależnych od nieprawidłowości stóp i stawu skokowo-goleniowego, zarówno w przypadkach fizjologii, jak i patologii. Zdaniem autorów tej pracy badanie pedobarograficzne powinno być stosowane znacznie szerzej i wraz z innymi metodami uzupełniać standardowy proces diagnostyki.

Key words:
foot, diagnostics, pressure, gait, pedobarography

Słowa kluczowe:
stopa, diagnostyka, ciśnienie, chód, pedobarografia

Correspondence address:
Jacek Lorkowski
tel. 606 452 887
e-mail: jacek.lorkowski@gmail.com

Introduction

The human body is a coherent unit in which pathologies concerning one organ or a system can cause disorders [1,2]. Accordingly, proper anatomical relations are an essential feature for their functions. Vesalius noted this fact in his work "De humani corporis fabrica". The correct structure of particular organs can affect the whole locomotor system, as well as it is a subject to changes in various pathologies [1,3,4]. There are many non-invasive examinations, which enable the description of motor system pathologies, such as physical examination, imaging or pedobarography [5,6,7]. None of them however, besides pedobarography, describes plantar pressures.
It should be noted, that the biomechanics changes during stance and gait, and this is why the measurements should be carried out in both cases [8]. We distinguish three types of pedobarography: static pedobarography (defining plantar pressure distribution during stance in the particular time), postural pedobarography (defining plantar pressure distribution during specified time period of the stance) and dynamic pedobarography (defining plantar pressure distribution during gait) [2,8].
The obtained result is shown as a pressure map, which enables a precise analysis of the forces acting on the sole, an assessment of the size of the contact area and the forces acting on the particular sole parts [5,9]. However, the methodology requires using a measuring platform, a treadmill, baroresistive sensors or isolated sensors. The interpretation of results obtained should be conducted by an experienced clinician, using a chosen foot region classification (the most popular are Blomgren, Cavanagh's, Kernozek's and Stess's classification). They include foot regions and differences between pressures in particular regions, that have been distinguished in the clinical anatomy [10,11,12,13].

It is well known, that the pedobarographic examination focuses mostly on the description of pathologies primarily concerning foot and ankle joint and both, children and adults, can be examined [14]. It is interesting that pedobarography was used also among animals [15,16]. Despite the fact, that a numerous treatment methods effectiveness was proven using pedobarography, it is tried

to broaden its application possibilities. In this article we present the possibilities of pedobarography application not only in orhopedics, in disorders primary independent from foot and ankle joint pathologies, but also in systemic diseases and medical fields other than orthopaedics. This article was based on the available literature and own experience as a result of over 10 000 examinations carried out since 1997. The articles were selected using PubMed database. The authors have searched for the keywords: „foot pressure distribution" and „pedobarography" separately and in combination with specific diseases or medicine fields. Out of over one thousand full-length articles of mostly English language, published or unpublished, cencerning pedobarography in various medical fields, only 96 were included. Studies concerning pedobarography as a general problem and case reports were excluded.

Pedobarography in diabetology

Many authors emphasise the usefulness of pedobarography in diabetology. The reliability of this examination in patients with diabetic neuropathy has found to be commensurate with a healthy population [17]. Diabetic angiopathy and neuropathy, together with increased plantar pressures (especially under the head of II and III metatarsal bone), can lead to non-healing skin ulcerations and even Charcot's arthroneuropathy. Conditions mostly related to diabetes mellitus, such as: neuropathy, microangiopathy and atherosclerosis are responsible for the pathophysiology of neuropathy [17-19,22]. The complex impact of the neurovascular insufficiency, inflammation, endothelilal disfunction, metabolic and autoimmune damage of the nerve fibers resulting in the damage of spinal cord and impaired pain processing in the central nervous system can easily lead to feet ulcerations and Charcot's arthropathy [20,21,22]. Therefore, many articles point out, that there is a necessity of a complex and multidisciplinary approach to diabetes-related feet pathologies and their early diagnostics. Unfortunately, too little centres of competence treat the "diabetic foot" in a recommended way. This also concerns western Europe [17]. Due to the fact, that not only skin and subcutaneous tissue, but also other connective tissues and bones, are involved in the process, among specialists taking care of those patients there are also orthopedists and podologists [18,19]. It was proven that the most loaded (with the highest plantar peak pressures) foot region in patients with diabetic polyneuropathy is the forefoot [13,23-25], although the results can be influenced by other foot deformities, such as the hammer toe deformity [25]. The pedobarography enables the selection of proper insoles and shoes, what together with diabetes control decrease a total risk of trophic lesions and development of full-symptomatic "diabetic foot". [13,23,24,25]. Moreover, pedobarography can be used as a screening examination in early diagnosis of diabetic polyneuropathy- it was shown, that biomechanical changes correlate with paresthesia and changes in impulse transmission in the sural nerve and in the common fibular nerve [26,27]. It is also important, that already in the impaired glucose tolerance stadium, although there are no symptoms of neuropathy, changed underfoot pressures can be observed [28]. Additionally, pedobarography has proved the effectiveness of particulate treatment methods of diabetic polyneuropahy [29].

Pedobarography in rheumatology

The examination of underfoot pressure distribution is also used in the diagnostics of "rheumatoid foot" [30,31]. The rheumatoid arthritis (RA) is a risk factor in the development of pain, due to deformation and inflammation including foot. Micro injuries of the joint cartilage, synovitis and constantly activated pro-inflammatory cytokines exacerbate mentioned problems. In patients with this disease, a 2-3-fold increase of underfoot pressures under each head of metatarsal bones, the flattening of the transverse arch, and the lateralization of maximal loads of the foot were stated, when compared to healthy population [31,32]. Additionally the observed changes are: higher pressures and increased contact area in the forefoot region. Patients with more advanced radiographic changes also showed higher values of maximal pressures in the forefoot in the static pedobarography, and under phalanges in the dynamic pedobarography [32]. Schmiegel et al. suggests, that in the case of rheumatoid arthritis pain did not correlate with the severity of destructive changes in the joints [33]. He has described biomechanical changes characteristic for RA, based on the group of 112 rheumatoid arthritis patients, divided into three groups depending on the degree of physical activity limitation. Average pressure values in the lateral forefoot and under the second metatarsal head were higher in the group with a good physical capacity, when compared to the controls and the moderate physical capacity group. Moreover, there were no significant differences in maximum force between the groups [33]. Choi et al. in his study concerning 72 patients suggests, that the validity of pedobarographic examination (both static and dynamic) is low [36], but according to the majority of articles, pedobarography is useful in the early diagnostics and detection of the disease [34,35]. In the early stages of rheumatoid arthritis, with minor feet deformations, the pedobarographic examination also enables the selection of suitable insoles or orthopaedic shoes (mostly to reduce plantar pressures in the forefoot region), while in the case of advanced changes it simplifies detailed planning of surgical treatment and then monitoring its results [37,38,39]. In rheumatology pedobarography was further applied in description of underfoot pressures in ankylosing spondylitis, gout (lower peak plantar pressures in hallux) [40] or psoriatic arthritis [41,42].

Pedobarography in neurology

Individual reports present the use of pedobarography in neurology. An analysis of pressure distribution, especially when walking or during gait, is useful in the evaluation of motor functions in Parkinson's disease. In the dynamic test, involving a group of 24 patients, a tendency to reduced impact at heel strike was found. Moreover, a loading level of this region correlated positively with the disease progression. Another characteristic feature of patients with Parkinson's disease is exerting higher relative loads in the forefoot area and their shift toward medial foot regions.

The authors also suggest, that this walking pattern could be a result of unsteadiness and imbalance, which are often observed in Parkinson patients [43]. It is very important and interesting, that pedobarography has been used in patients with multiple sclerosis (MS). It turns out to be a useful tool for detecting motor impairment, even before first visible gait disorders. This may be helpful in predicting the course of the disease and the choice of rehabilitation strategy, as well as in monitoring treatment effectiveness [44]. Another important issue concerning neurology and causing numerous motor disorders, is ischemic stroke. Associated hemiplegia and hemiparesis significantly affect the distribution of underfoot pressures [47,48]. What is more, imbalance can be observed [47,48]. All mentioned phenomena exacerbate the severity of disability and for this reason, an appropriate post-stroke rehabilitation is very important. Monitoring the progress of rehabilitation and assessment of new rehabilitation and treatment methods are the main applications of pedobarography in this particular case. It is also interesting, that in this patient group the differences, depending on the hemisphere affected by the stroke, were observed. Patients with infarct of the right middle cerebral artery showed a slower and more asymmetrical gait, than patients with the left middle cerebral artery infarct [49]. Using pedobarography, the efficiency of following treatment methods was confirmed: deep dry needling [50], closed kinetic chain exercise [51], the use of robotic-assisted gait [52].

Also a group of 15 patients with a post-stroke hemiparesis has undergone a pedobarographic examination. Results may be helpful in assessing gait asym-

rehabilitation [45].

Pedobarography in otorhinolaryngology

The principle function of the balance system is to provide a stable, standing posture of human body in such a manner, that the vertical projection of the centre of gravity does not move beyond the anatomical boarders of the base of support [53]. An interesting issue is posturography, an area dealing with estimation of stability and other conditions affecting balance. Its main application is otorhinolaryngology, although it can be also used in neurology among patients with increased fall risk (due to sensation and strength impairment or cerebellar atrophy), for example stroke or multiple sclerosis [46,54]. To evaluate the sway (that may take place in the sagittal and coronal planes), it is necessary to draw up a stabilogram or statokinesigram, respectively illustrating shifts in the centre of gravity and movements occurring in the centre of pressure [53,55]. In this evaluation pedobarography has been applied. The sway velocity was examined, depending on the foot posture index, foot size and plantar pressure in terms of unilateral stance. A total of 236 feet of 118 patients were classified as: prone, normal and supine. There were almost no differences in the study group with open eyes. However, during attempts with eyes closed, it turned out, that the greatest incidence of sway occurs in people with prone feet. Also patients with flatfoot are more instable than those with normal-arched feet. Moreover, the severity of flatfoot does not influence the sway. In this group the foot insoles may support the proper foot and body position [56]. The postural sway velocity can be also affected by the force-time-area integral and higher values of Foot Posture Index (FPI) [57,58]. Błaszczyk suggests, that the conventional method of the study execution may result in incomparable and thus unreliable results. In his article he presents new methods to assess sway velocity- the sway directional index, the sway directional ratio and the sway vector [59]. It shows, that this field is still being explored.

Pedobarography in obstetrics and gynaecology

Underfoot pressures are also examined in pregnant women, because of the physiological shift of the centre of gravity. According to the preliminary study carried out on 15 pregnant women, many of them suffer from lower limb pain and backache, especially in the third trimester, when the center pressure displaces torwards the heel [60]. Pedobarography has been applied in order to assess the specific gait changes, caused by this condition. Increased contact area of the foot with the measuring platform and increased loads in the hindfoot area and lateral foot region were described. The relative decrease of loads were observed in the medial foot region [61]. Another study analysed changes occuring in plantar pressures during the whole pregnancy period in 6 women. The pressures reduced gradually within 9 months in the medial rearfoot, maximun force was found to be higher in the 2nd than 1st thrimester as well as the contact area in the lateral rearfoot and midfoot [62]. Results of pedobarographic examination enable the selection of proper insoles, which are helpful in reducing overloads, lower limb pain and backache [61,63]. One of the studies describes a group of 35 women in the third trimester of pregnancy, in which static and dynamic pedobarography together with the Visual Analogue Scale (VAS) were used, in order to asses underfoot pressures and pain severity among pregnant woman. Additionally, changes in the balance system were evaluated. It turned out, that the pressures are higher within the right forefoot area. Also a higher sway velocity in the sagittal plane was observed. The authors believe, that these problems can be effectively treated with proper footwear and exercises [64]. Moreover, changes in underfoot pressure distribution and pain resolve after the delivery [65].

Pedobarography in orthopaedics, in conditions primary independent from foot and ankle joint pathologies

The locomotor system, as a functional unit, provides the proper motor and support function for the human body [2]. Changes occurring in singular parts of the whole unit affect many other components. Below we present examples of pedobarography usage in conditions primary independent from foot and ankle joint pathologies, i.e. diseases of the spine, hip joint and knee joint. These pathologies affect the underfoot pressure distribution and find their "reflection" on pedobarographic platforms.

A very important symptom, accompanying spine diseases is a lumbar pain. One of the studies enrolled patients with scoliosis and various types of degenerative spinal column changes, who complained of pain in the lumbar region. Increased maximal pressures were found in H foot region on the side of pain (ipsilateral), and on the opposite side (contralateral) in MT3 and MT4 regions (classification according to Blomgren), among patients with osteoarthritis. Moreover, the centre of gravity has shifted to the front. In patients with scoliosis higher maximal pressures were observed in H and T foot areas on the side of the scoliosis, and on the contralateral side in the MT5 foot area (according to Blomgren) [66,67]. Researches, published so far, also describe changes in plantar pressure distribution in patients with scoliosis (pressures increase mostly in the hindfoot and forefoot area) [68,69], shift of the centre of gravity, confirm, that pedobarography is an appropriate tool for diagnosing [69,70] scoliosis and agree, that these pathologies influence the ankle-foot complex [68].

The most common hip pathology is osteoarthritis (OA). During its course, there is an impairment of motor function. OA can lead to significant pain, resulting in a limitation of social functioning of the patient. Main, measurable with pedobarography, pathologies result from the asymmetry in load-bearing between affected and healthy lower limb- especially after arthroplasty reduced loads on the operated limb were observed (this pathology resolved after one-month rehabilitation) as well as differences in individual lenght of the steps (persisted pathology) [71,72]. The effectiveness of rehabilitation in OA patients was confirmed using pedobarography [73], as well as normalisation of underfoot pressures after total hip arthroplasty [74,75]. It should be emphasized, that all authors agree about the usefulness of pedobarographic examination in monitoring the course of the disease, assessing an effectiveness of surgical treatment and rehabilitation [71,72,73,74,75].

In the case of the knee joint patients with following pathologies have been described: knee osteoarthritis [76,77,78,80], haemophilia [81,82], meniscus injury [83] and anatomical defects of the knee [84,85]. In patients with knee osteoarthritis lower pressures in the right hindfoot and forefoot were observed. The severity of pain (measured with VAS) negatively correlated with the values of maximal plantar pressure. There is also a difference in obtained results, that radiographic changes can correlate with center of pressure among these patients [77,78].

The authors agree about the usefulness of pedobarography in the diagnostics and monitoring of gonarthrosis as well as monitoring biomechanical effects of orthoses [76,77,78,80]. When it comes to haemophilia, a case of a patient with knee flexion contraction was described. With pedobarographic examination, carried out before treatment, a significant asymmetry of underfoot pressure distribution was stated. Moreover, their normalization could be observed during rehabilitation [81]. It is notable that with functional orthoses a total number of ankle bleedings decreased in haemophilic patients [82]. Another factor affecting plantar pressures are changes in knee anatomy. Postural pedobarography showed decreased pressure values in H foot region and their increase in MT2, MT3 and MT4 areas (according to Blomgren) among patients with traumatic or degenerative anatomical changes in the knee joint [83]. Similarly varus knee deformity determines the decrease of pressures in the H region and their growth in MT4 and MT5 zones according to Blomgren [84]. In turn, medial meniscus injuries

also cause decreased pressures in the H region, but their values increase in MT2 and MT3 foot areas in classification according to Blomgren. Additionally the reduction of contact area was found [85].

Pedobarography in researches concerning loading

The load is one of the factors, that can change correct foot function and plantar pressure distribution. Its impact on the musculoskeletal system biomechanics and on the possible risk of injury was examined primarily for the armed forces and soldiers, who often have to travel with a considerable weight [86]. One of the studies showed increased plantar pressures, regardless of the foot arch type [87]. However, this study had also its limitations. One of them was the lack of standardization regarding footwear- every person tested had worn his or her own combat shoes. Also the limb-bearing time was short. An interesting study was carried out in Germany. A group of 31 male soldiers was enrolled in the study in order to assess plantar pressures depending on an amount and a way of load carrying. In this case both static and dynamic pedobarography was applied. The study showed an increase of the superficial pressure and the contact area in the midstance. Also the load distribution affected the pressures- higher values were achieved when carring the riffle over the shoulder [88]. Moreover, plantar regions with higher pressures differ depending on the load carried [89,90].

Pedobarography in sports medicine

Due to an increased emphasis on social health and more common sport activity, subjects practicing jogging and nordic walking are being examined [91-95]. Pedobarographic measurements are helpful in designing proper shoes and inserts, simultaneously focusing on overloaded foot zones in particular pathologies and sport disciplines. Moreover, it is essential for sports medicine to analyse and optimize biomechanical aspects of the locomotor system functioning, using static and dynamic pedobarography. With the analysis of plantar pressures it is possible to produce appropriate footwear and orthoses, that eliminate non-physiological pressures, reduce pain and improve compfort during activity. It should be also noted, that nordic walking was found to have a positive influence on underfoot pressure distribution [96].

Pedobarography in occupational medicine

The pedobarographic analysis is also used in occupational medicine in order to control the stress loads at the workplace. A specific role of plantar pressure distribution can be observed not only in the technology of orthopaedic footwear, but also of the sports and everyday footwear. Pedobarography can be used as well in scientific analyses of engineering constructions during designing and assessing the function of lower limb prothesis [2].

Summary

To conclude, pedobarography as a cheap and non-invasive method should be applied more widely. The result of this study is a direct representation of the joint chain, physiologically ending in the foot area. It facilitates an assessment not only of the foot biomechanics, but of the entire musculoskeletal system. With pedobarographic examination it is possible to analyse particular pathologies, the influence of systemic diseases on the human body and monitor the course of treatment and rehabilitation.

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