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PRACA POGLĄDOWA
REVIEW

The applications of posturography in selected neurological disorders

Zastosowania posturografii w wybranych schorzeniach neurologicznych

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ABSTRACT

Posturography is one of the objective methods of evaluating human balance. Human balance is the ability to maintain a vertical center of mass (COM) in the support area (base of support – BOS). COM in a homogeneous gravitational field coincides with the center of gravity (COG). The postural control system (PCS) maintains the COG projection in the support area and counteracts the external forces (gravity and inertia force) that destabilize the posture of the human body. Minimizing body deflection is controlled by the central nervous system (CNS). External stimuli are received through visual, atrial, proprioceptive and exteroceptive systems. The information is transmitted to the CNS, which, means of the feedback system, controls the motion system to minimize the risk of falls. The aim of this work is to present the types of posturography: static, dynamic, and follow-up posturography, their use in the objective diagnosis of imbalances, as a tool for rehabilitation and for monitoring the progress of treatment in Parkinson's disease and patients after stroke.

KEYWORDS

stroke, rehabilitation, balance, posturography, Parkinson's disease

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STRESZCZENIE

Posturografia jest jedną z obiektywnych metod służących do oceny układu równowagi człowieka. Równowaga człowieka to zdolność do utrzymywania pionowego rzutu środka masy ciała (*center of mass* – COM) w polu powierzchni podparcia (*base of support* – BOS). COM w jednorodnym polu grawitacyjnym pokrywa się z rzutem środka ciężkości ciała (*center of gravity* – COG). System kontroli postawy (*postural control system* – PCS) utrzymuje rzut COG w BOS oraz przeciwdziała siłom zewnętrznym (sile grawitacji i bezwładności), które wpływają destabilizująco na postawę ciała człowieka. Minimalizowanie wychwiań kontrolowane jest przez ośrodkowy układ nerwowy (*central nervous system* – CNS). Poprzez narządy przedsionkowy i wzroku oraz eksteroreceptory i proprioreceptory odbierane są bodźce zewnętrzne. Informacje o nich przekazywane są do CNS, który poprzez reakcje zwrotne steruje układem ruchu tak, by minimalizować ryzyko upadków. Celem pracy jest zaprezentowanie trzech typów badań posturograficznych: statycznego, dynamicznego i nadążnego, a także przedstawienie zastosowań posturografii do obiektywnej diagnostyki zaburzeń równowagi oraz jako metody służącej do rehabilitacji i monitorowania postępów terapii w chorobie Parkinsona oraz u osób po udarze mózgu.

SŁOWA KLUCZOWE

udar mózgu, rehabilitacja, równowaga, posturografia, choroba Parkinsona

INTRODUCTION

Posturography is one of the objective methods of evaluating the human balance system (both in healthy and unhealthy people) [1]. Human balance is the ability to maintain a vertical projection of the center of mass (COM) of the body in the base of support (BOS) surface, which is determined by the contours of the feet adjacent to the ground [2,3,4]. COM in a uniform gravitational field coincides with the projection of the center of gravity (COG) of the body. The vertical setting of the body axis in relation to BOS allows the body to maintain an upright position, which is characteristic for a human being [5,6]. Maintaining postural stability is associated with the need to constantly minimise body tilts so that the COG projection does not move beyond BOS [2,8]. The postural control system (PCS) maintains the COG projection in BOS and counteracts external forces (gravity and inertia) that destabilize the posture of the human body [9]. Minimizing sways is controlled by the central nervous system (CNS). The organ of vision, the vestibular system, exteroceptors and proprioceptors receive external stimuli [5,7]. Information about the stimuli is transferred to CNS, which controls the musculoskeletal system through centrifugal pathways (mainly by influencing the tension of postural muscles, especially the calf muscles) to minimize the risk of falls [8]. The balance can be altered by various, temporary or permanent factors [10]. The study aims to present three types of posturographic examinations: static, dynamic and follow-up posturography, the use of posturography for the objective diagnosis of balance disorders and as a method for rehabilitation and monitoring the progress of therapy in Parkinson's disease and people after stroke.

Types of posturographic examinations

Static posturography

Static posturography is a test for which one or two platforms with dimensions of 50 × 50 cm are used. Its strain gauges measure the pressure forces and moments of forces exerted on the ground by the feet of a patient. In the corners of the platform, there are supports with sensors that register changes in the position of COG on the platform. Posturography is usually performed barefoot and begins with the patient being placed on the platform. The test is technically easy to perform and does not require prior patient preparation. Measurements are taken successively in a standing position, with eyes open, and then with eyes closed. This makes it possible to compare the subject's balance with and without visual control [11]. The patient's task during the basic examination is to maintain a static, upright position on the platform for a certain period. The examined person is recommended to focus their eyes on one point, located at a distance of about 1 meter [5,12]. Different positions are also used during the examination, e.g. standing on one leg (left or right), then the foot of the supporting leg is set so that in the sagittal plane the center of the heel is in line with the second metatarsal bone, and the line connecting the medial and the lateral malleolus of this foot is 4 cm beyond the intersection of the sagittal and coronal planes on the posturography platform. The rest of this test is the same as in the bipedal position. The obtained results are transferred to the computer, and then the location of the center of pressure (COP) of the feet is calculated, which in static positions is identical to the COG projection on the support plane. As a result, a statokinesiogram is obtained, i.e. a graph of COP swings (Figure 1) [5,12].

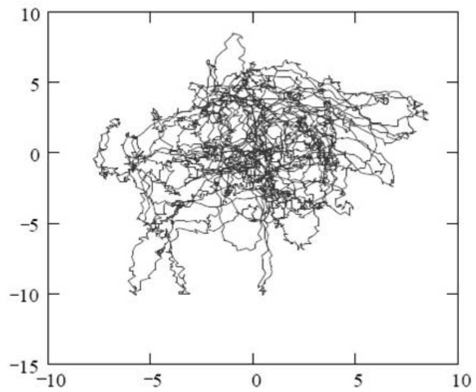

Fig. 1. Example of recording of the center of pressure (COP) movements registered on tensometric platform (authors' source).
Ryc. 1. Przykładowy zapis przemieszczeń środka nacisku stóp (COP) zarejestrowany na platformie tensometrycznej (materiał własny).

The parameters of the statokinesiogram, i.e. a graphical representation of the foot COP sways, which are taken into account when interpreting the obtained results are:

- Curve length – the length of the path travelled by COG
- Range of swings – is determined in the sagittal and frontal planes, the measure of swing ranges is the difference between the extreme deviations of COG along the corresponding axis
- Area of the developed statokinesiogram – a computer-calculated area of the polygon obtained by connecting the extreme points of the statokinesiogram
- Radius – calculated by enclosing the sway points in a circle or ellipse
- Average velocity – calculated based on the COG travel time (Figure 2) [5].

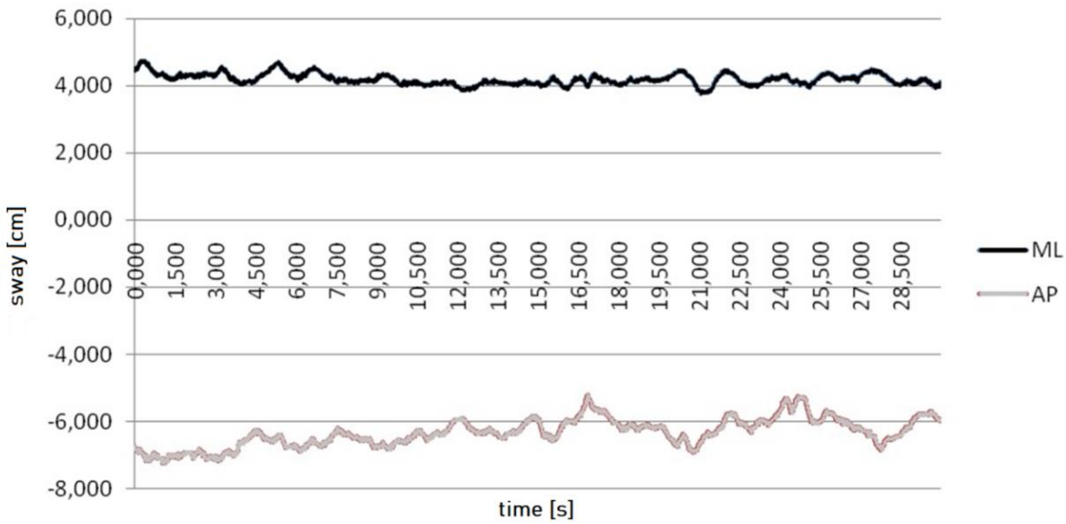

Fig. 2. Averaged recording of changes in the center of pressure (COP) position during free stand with open eyes (authors' source). AP – anterior-posterior plane (sagittal); ML – medial-lateral plane (frontal).
Ryc. 2. Uśredniony zapis zmian położenia środka nacisku stóp (COP) podczas próby swobodnego stania obunóż z oczami otwartymi (materiał własny). AP – płaszczyzna przednio-tylna (strzałkowa); ML – płaszczyzna przyśrodkowo-boczna (czołowa).

The following analytical methods are used to analyze statokinesiogram data:

1. Percentage determination of the amount of COG presence time in each of the quadrants of the coordinate system formed by the sagittal and frontal planes, thanks to which it is possible to determine the load distribution of the lower limbs and determine the patient's natural posture.
2. The Fast Fourier Transformation (FFT) method, which is used to determine the frequency of COG movement specific to a given person [5].

Dynamic posturography

Dynamic posturography allows the precise determination of balance problems. An important element that distinguishes this test from a standard static test is forcing the examined person to react under the influence of a sudden movement of the platform or other stimulus that destabilizes the patient's body [5].

Several types of tests are used in this examination:

1. Motor Control Test (MCT) – assesses the patient's ability to quickly and automatically regain a stable posture after an unexpected external provocation, destabilizing the static position. Destabilization is achieved by changing the COP position performed by the subject (e.g. in an attempt to tilt the body as far forward or backward as possible; Figure 3A and 3B) or through a sequence of small, medium and large forward and backward shifts of the platform that cause an immediate postural response. The measurements include time, force, and lateral symmetry of the response [5,13].

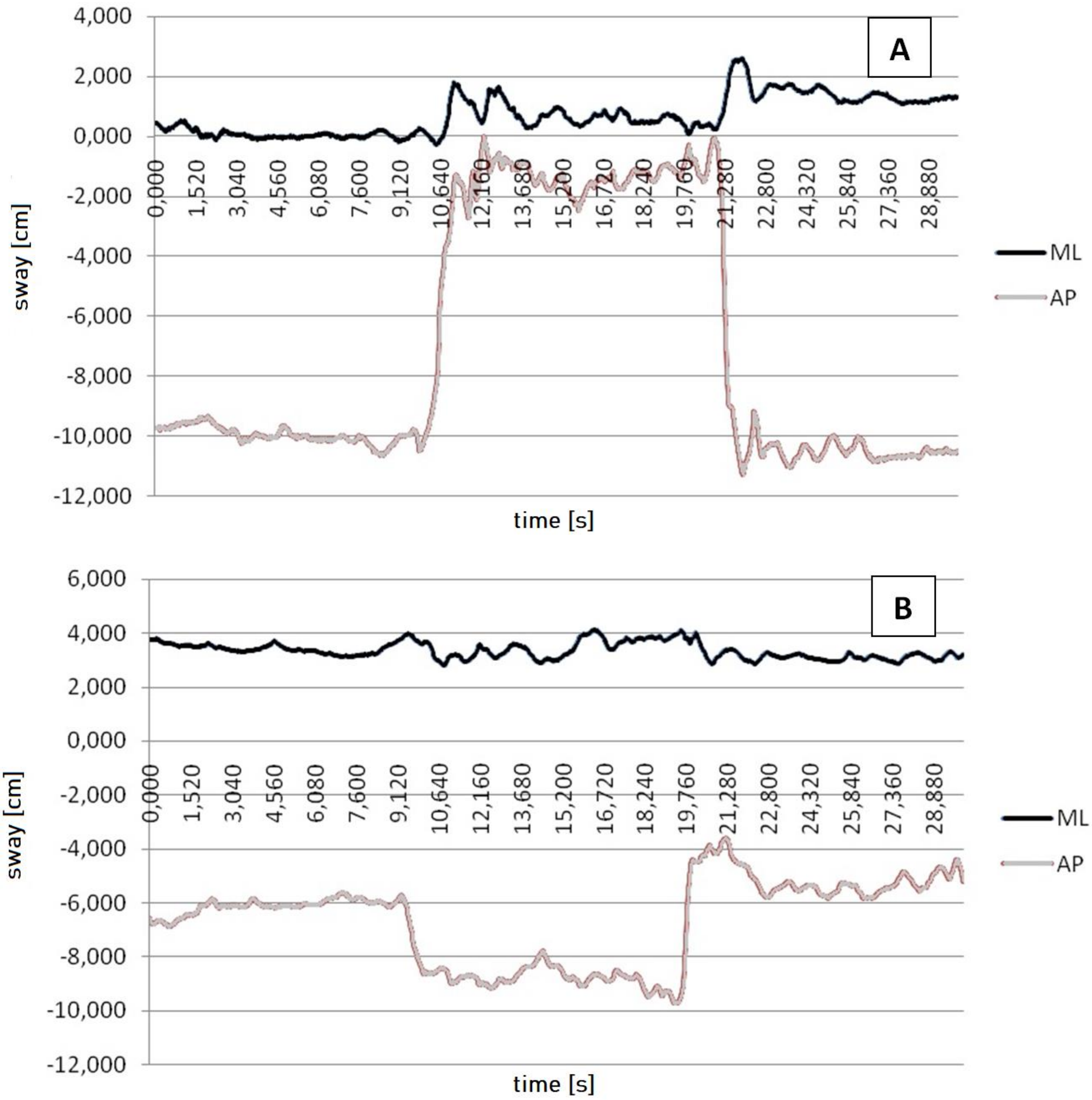

Fig. 3. Averaged recording of changes in the center of pressure (COP) position during free deflection (A) forward and (B) backwards with open eyes (authors' source). AP – anterior-posterior plane (sagittal); ML – medial-lateral plane (frontal).
Ryc. 3. Uśredniony zapis zmian położenia środka nacisku stóp (COP) podczas próby swobodnego wychylenia w przód (A) i w tył (B) z oczami otwartymi (materiał własny). AP – płaszczyzna przednio-tylna (strzałkowa); ML – płaszczyzna przyśrodkowo-boczna (czołowa).

2. The Sensory Organization Test (SOT) consists of 6 different tests with a gradual increase in difficulty:
   1) Eyes open, stable ground and visual reference point.
   2) Eyes closed, stable ground.
   3) Eyes open, stable ground, movement of visual reference point.
   4) Eyes open, ground movement, stable visual reference.
   5) Eyes closed, ground movement.
   6) Eyes open, ground movement and visual reference point movement [6].

The test is used to determine the patient's ability to:
– effectively use information from the eyes, vestibular system and proprioceptors
– suppress information that is inappropriate at the moment. For example, the information obtained from the proprioceptors about the angular position of the ankle joint is distorted when the ground is swaying in the sagittal plane. Closing the eyes or changing the position of the reference point hinders the feedback process in maintaining balance.

The manipulation of sensory information is used to test a person's ability to adapt to changing conditions in the environment and to maintain postural control. This test is also employed to assess the risk of falls in patients [5].

3. The Adaptation Test (ADT) evaluates the patient's ability to modify equivalent reactions and the ability to minimize body sway when the ground moves, unpredictably tilting the patient diagonally down or up. The force of the platform movement must be estimated so that it can cause postural instability in a given patient. This test is a simulation of conditions occurring in everyday life, such as moving on irregular surfaces [14,15].

Dynamic posturography is a test that utilises modern technological possibilities to obtain the best conditions for examination and therapy. During the posturographic examination, the following can be additionally used: virtual reality (created by computer software), multi-channel sound, glasses with integrated screens (head-mounted display – HMD) and the patient's sense of acceleration and movement transfer. Additional elements that evoke visual stimuli make it possible to induce balance disorders in a person participating in the test through not always true information about the vertical, or for example, by provoking nystagmus as a result of optokinetic stimulation. They also make it possible to induce postural reactions – the examined person tries to counteract the induced disorders by controlling muscle tension [5,16,17,18].

When standing on the posturographic platform, the patient can control the movements of the body in a computer game, during for example, skateboarding, skiing or performing other activities. The muscles responsible for maintaining body posture are strengthened. A positive effect on the functions of the balance and deep sensation systems is observed. The results obtained in the game, the element of competition and changing, e.g. images on the monitor screen, are additional elements thanks to which the patient approaches the task with greater motivation and enthusiasm. This form of training has many advantages, including the fact that the risk of the patient falling and the risk of injury associated with falls are largely eliminated [19,20].

Follow-up posturography

Follow-up posturography is based on visual feedback. The patient observes the current position of COP on the monitor and directs its position so that his point is as close as possible to the moving directional point. The examined person performs the above-mentioned task by appropriately moving the body under the control of their eyesight.

At the beginning of the examination, the average position of the COP point in the patient in a standing position is determined, thanks to which it is possible to properly dose the moving directional point and compare it with the COP point obtained during the main part of the examination. Then the subject makes a maximum forward and backwards lean, without taking their feet off the platform. On this basis, the possible range of movement of the directional point in the sagittal plane is selected. It was assumed that precise movement reflecting the direction point requires 66% of the maximum body tilt. On the other hand, the range of body movement in the frontal plane requires the transfer of 2/3 of the body weight to the left or right lower limb.

In the proper follow-up posturography test, we distinguish several stages:

- Initial stage (unregistered) – transition from the resting position to the maximum tilt to the right
- Second stage (recorded) – movement of the tested COG with the direction point, which makes a clockwise circle (30 seconds)
- Intermediate stage – the patient's maximum tilt to the left and the change of the tilt direction to the anti-clockwise direction
- The last stage – movement as in the second stage with the opposite direction of movement.

The parameter of maximum tilt in the sagittal axis measured in this examination can be used to diagnose balance disorders [21].

The use of posturographic examinations in selected neurological diseases

Patients with Parkinson's disease

In Parkinson's disease, balance disorders are not the most specific symptom, but they play an important role in the course of this disease. They occur in 96% of patients and affect the functioning of patients in everyday life; they are also the main cause of disability. Posturography makes it possible to determine the degree of their severity at an early stage of the disease, and at the same time to indicate which of the balance control systems is the cause of the problem and what effect the drugs taken by the patient have on maintaining balance [22,23].

Posturography in a patient with Parkinson's disease is utilised to objectively quantify postural instability. Studies conducted by Zawadka et al. [24] showed that the above-mentioned patients exhibit a significant deterioration in stabilogram parameters compared to healthy people in a similar age range and that the length of the stabilogram in the frontal plane is a sensitive indicator of postural instability in the elderly population.

The advantage of posturography is to obtain objective, repeatable results. It has been employed, e.g. for the assessment of deep brain stimulation (DBS) using high frequency in patients with advanced Parkinson's disease. DBS was a supplement to pharmacotherapy. Posturography enabled an objective comparison of this method of treatment and its impact on balance disorders and body posture reactions of patients during the use of DBS and when DBS was stopped [25].

Posturography combined with modern technological possibilities, such as game consoles, are used to rehabilitate patients with Parkinson's disease. Innovative solutions make it possible to increase the attractiveness of training by adjusting the degree of difficulty and arousing the patient's interest, e.g. by including their own movements in the virtual environment [26]. These games utilise visual feedback, which gives good rehabilitation effects in patients with Parkinson's disease [23].

Posturography is also employed to compare the effects of balance training by means of visual feedback with those of conventional balance training. Posturographic balance analysis using a feedback platform enables postural assessment in quantitative terms and allows a detailed study from the dynamic side. The results obtained from the feedback training of balance in patients with Parkinson's disease have shown that computer-assisted exercises can be at least as effective as standard treatment. Such training can be a good alternative to individual exercises with the patient; it also allows the rehabilitation process to be conducted at home [26].

A posturographic examination can be additionally combined with an electroencephalographic (EEG) examination in order to determine how the improvement in body balance affects the activity of the cerebral cortex during a given examination [26]. To determine the location of the source of brain activity, the results obtained from the EEG examination are combined with the recorded results from magnetic resonance imaging [27].

Patients after stroke

Stroke patients present with a variety of clinical symptoms, including paresis, muscle tone disorders, superficial and deep sensation disorders, cognitive disorders, vegetative system disorders, emotional disorders, speech disorders, amblyopia and loss of sight [28].

Disorders resulting from a stroke lead to various degrees of disability, a frequent consequence of which is locomotion impairment. Disturbed body posture control is considered to be the main problem of this group of patients, and the consequence of this disorder is the occurrence of frequent falls. Improving body balance is an important element when working with a patient because good control of body posture is a condition for effective and safe movement [29].

Posturography as an objective test is used to assess the effectiveness of rehabilitation by utilising the method of proprioceptive neuromuscular facilitation (PNF) of patients after a stroke. This examination allows assessment of the patient's reactions, especially reactions to correcting body posture and maintaining balance [30].

The posturographic examination is employed to compare and analyze stabilogram parameters in healthy people and in people after a stroke before and after exercises to improve balance, and it is also used to assess the eye-hand coordination factor [31].

Posturography in the Tetrax device (tetra-ataxiometric posturography) in stroke patients is employed as a research tool and as a training method. The obtained results allow the analysis of, among others, the fall rate, body weight distribution index and stability index. It allows conclusions to be drawn about imbalances. The parameters measured with the Tetrax device allow an objective assessment and comparison of balance training using the Tetrax training program and a training program utilising virtual reality. Based on the analysis, it was confirmed that Tetrax as a training program is a good alternative for patients with proprioceptive disorders, while a program using virtual reality can be employed to improve the balance of people with preserved sensory functions [32,33].

Posturography also allows monitoring of the effects of neurodevelopmental treatment Bobath (NDT Bobath). The main assumption of this method in patients after stroke is the correct distribution of body weight during the first 12 months after the onset of the disease [34].

Movement impairment after a stroke often leads to an increased risk of falls, especially when changing the body position in space, for example from sitting to standing. The causes of this disorder are: low muscle strength, poor postural control and poor perception of sensory stimuli. Many tests assess the degree of disorders occurring after a stroke: the muscle endurance test, sit-stand-sit test, equivalent static and dynamic tests, or the Berg Balance Scale. Sometimes the tasks that the patient must perform during the above-mentioned examinations exceed the patient's capabilities, and the correct assessment of balance and other parameters is impossible or unreliable. Therefore, a new system for evaluating the control of the patient's body posture was created [30,35]. This system, called the multi-utility balance assessment and training system (MUBATS), utilises a special device that allows patients to safely perform the squat-stand test thanks to a special sliding platform. This method allows the symmetry and balance of the patient to be maintained; therefore, it can be used even in the early stages of the disease, which is not possible with other tests. For a more accurate assessment, this method can be combined with a posturographic examination and during the squat-stand test, the following parameters can be obtained: COP, average sway, path length, surface, maximum sway, and speed of movement. These parameters are calculated automatically by the computer [35].

The MUBATS scoring system is helpful for stroke patients who are unable to perform the sit-stand-sit test. Thanks to the special apparatus used for the test, the patient has full stability during the test. The direction of the acting forces and coordination of the hip and knee joints during the sit-stand-sit test and the squat-stand test are practically the same; thus, the posturographic examination used during the squat-stand test to some extent reflects the real control of the body position [35].

CONCLUSIONS

Posturography can be utilised in patients with neurological disorders in a conventional way as a diagnostic method as well as for therapeutic purposes using modern technologies.

Posturography is an objective diagnostic tool that also allows assessment of the effectiveness of treatment (pharmacological and non-pharmacological); moreover, in combination with various technologies, it can be employed as a method of kinesiotherapy.

Balance disorders, and consequently falls and injuries, are important elements that lead patients to limit their independence in everyday life, and consequently, to develop a progressive disability, forcing the use of orthopaedic equipment, including elbow crutches, walkers, and wheelchairs, to partially replace lost gait functions. Thanks to numerous advantages, perhaps posturography will become an increasingly more used method, allowing safe and effective diagnosis and then rehabilitation of people with neurological and musculoskeletal disorders, due to eliminating the risk of falls and injuries during its use and the attractiveness of exercises.

Author's contribution

Study design – A. Oczadło, E. Matusik, B. Lewicka, U. Kowacka
Data collection – A. Oczadło, E. Matusik
Manuscript preparation – B. Lewicka, U. Kowacka, E. Matusik
Literature research – A. Oczadło, B. Lewicka, E. Matusik
Final approval of the version to be published – E. Matusik

REFERENCES

1. Zamysłowska-Szmytke E., Janc M., Ławnicki K., Śliwińska-Kowalska M. Zastosowanie posturografii dla oceny układu równowagi dla potrzeb medycyny pracy. Med. Pr. 2022; 73(2): 143–150, doi: 10.13075/mp.5893.01164.
2. Paszko-Patej G., Terlikowski R., Kułak W., Sienkiewicz D., Okurowska-Zawada B. Czynniki wpływające na proces kształtowania równowagi dziecka oraz możliwości jej obiektywnej oceny. Neurol. Dziec. 2011; 20(41): 121–127.
3. Olejarz P., Olchowik G. Rola dynamicznej posturografii komputerowej w diagnostyce zaburzeń równowagi. Otorynolaryngologia 2011; 10(3): 103–110.
4. Kuczyński M., Podbielska M.L., Bieć D., Paluszak A., Kręcisz K. Podstawy oceny równowagi ciała: czyli co, w jaki sposób i dlaczego powinniśmy mierzyć? Acta Bio-Opt. Inform. Med. 2012; 18(4): 243–249.
5. Błaszczyk J.W., Czerwosz L. Stabilność posturalna w procesie starzenia. Gerontol. Pol. 2005; 13(1): 25–36.
6. Rak J., Fajkiel K., Walkowiak K., Błędowska S., Badiuk N. Impact of physical activity on balance in people over 65 years of age. J. Educ. Health Sport 2017; 7(7): 1004–1016, doi: 10.5281/zenodo.999558.
7. Hebert J.R., Manago M.M. Reliability and validity of the computerized dynamic posturography sensory organization test in people with multiple sclerosis. Int. J. MS Care 2017; 19(3): 151–157, doi: 10.7224/1537-2073.2016-027.
8. Sobera M. Charakterystyka procesu utrzymywania równowagi ciała u dzieci w wieku 2–7 lat. Studia i monografie, nr 97. Wyd. AWF Wrocław 2010.
9. Fonseca P., Sousa M., Sebastião R., Goethel M., Barralon P., Idigoras I. et al. Equimetrix device: criteria based validation and reliability analysis of the center of mass and base of support of a human postural assessment system. Sensors (Basel) 2021; 21(2): 374, doi: 10.3390/s21020374.
10. Li Causi V., Manelli A., Marini V.G., Cherubino M., Meccariello L., Mazzacane M. et al. Balance assessment after altering stimulation of the neurosensory system. Med. Glas. (Zenica) 2021; 18(1): 328–333, doi: 10.17392/1324-21.
11. Wiśniowska-Szurlej A., Ćwirlej-Sozańska A., Wilmowska-Pietruszyńska A., Sozański B. The use of static posturography cut-off scores to identify the risk of falling in older adults. Int. J. Environ. Res. Public Health 2022; 19(11): 6480, doi: 10.3390/ijerph19116480.
12. Ćwirlej-Sozańska A., Wilmowska-Pietruszyńska A., Guzik A., Wiśniowska A., Drużbicki M. Ocena przydatności wybranych skal i metod stosowanych w ocenie równowagi i sprawności fizycznej seniorów – badanie pilotażowe. Prz. Med. Uniw. Rzesz. Inst. Leków 2015; 1: 8–18.
13. Vanicek N., King S.A., Gohil R., Chetter I.C., Coughlin P.A. Computerized dynamic posturography for postural control assessment in patients with intermittent claudication. J. Vis. Exp. 2013; 82: e51077, doi: 10.3791/51077.
14. Honaker J.A., Converse C.M., Shepard N.T. Modified head shake computerized dynamic posturography. Am. J. Audiol. 2009; 18(2): 108–113, doi: 10.1044/1059-0889(2009/09-0012).
15. Karim H., Fuhrman S.I., Sparto P., Furman J., Huppert T. Functional brain imaging of multi-sensory vestibular processing during computerized dynamic posturography using near-infrared spectroscopy. Neuroimage 2013; 74: 318–325, doi: 10.1016/j.neuroimage.2013.02.010.
16. Tossavainen T., Juhola M., Pyykkö I., Aalto H., Toppila E. Development of virtual reality stimuli for force platform posturography. Int. J. Med. Inform. 2003; 70(2–3): 277–283, doi: 10.1016/s1386-5056(03)00034-0.
17. Rosiak O., Puzio A., Kaminska D., Zwolinski G., Jozefowicz-Korczynska M. Virtual reality – A supplement to posturography or a novel balance assessment tool? Sensors (Basel) 2022; 22(20): 7904, doi: 10.3390/s22207904.
18. Peters J.F. Computerized dynamic posturography (CDP) and the assessment of balance with active head movements. J Korean Balance Soc. 2007; 6(2): 243–247.
19. Józefowicz-Korczyńska M., Walak J., Szczepanik M., Grzelczyk W.L., Rosiak O. Ocena zastosowania wirtualnej rzeczywistości jako metody fizjoterapii w uszkodzeniu obwodowym narządu przedsionkowego. Otorynolaryngologia 2014; 13(1): 51–57.
20. Strzecha M., Knapik H., Baranowski P., Pasiak J. Człowiek zazwyczaj ma dwie nogi – ujęcie stabilograficzne. W: J. Mosiewicz [red.]. Czynniki ryzyka i profilaktyka w walce o zdrowie i dobrostan. Wyd. Neurocentrum. Lublin 2008, s. 155–165.
21. Kidoń Z., Fiołka J. Ocena postępów rehabilitacji za pomocą testu stabilografii nadążnej. Prz. Elektrotech. 2014; 90(9): 50–53.
22. Güler S., Bir L.S., Akdag B., Ardıc F. The effect of pramipexole therapy on balance disorder and fall risk in Parkinson's disease at early stage: clinical and posturographic assessment. ISRN Neurol. 2012; 2012: 320607, doi: 10.5402/2012/320607.
23. Sebastia-Amat S., Tortosa-Martínez J., Pueo B. The use of the static posturography to assess balance performance in a Parkinson's disease population. Int. J. Environ. Res. Public Health 2023; 20(2): 981, doi: 10.3390/ijerph20020981.

24. Zawadka M., Klawe J.J., Zalewski P., Bitner A., Pawlak J., Tafil-Klawe M. et al. Ocena wybranych parametrów stabilności postawy i funkcji poznawczych osób z chorobą Parkinsona po 60 r.ż. Hygeia Public Health 2013; 48(1): 80–85.
25. Nilsson M.H., Fransson P.A., Jarnlo G.B., Magnusson M., Rehncrona S. The effects of high frequency subthalamic stimulation on balance performance and fear of falling in patients with Parkinson's disease. J. Neuroeng. Rehabil. 2009; 6: 13, doi: 10.1186/1743-0003-6-13.
26. van den Heuvel M.R., van Wegen E.E., de Goede C.J., Burgers-Bots I.A., Beek P.J., Daffertshofer A. et al. The effects of augmented visual feedback during balance training in Parkinson's disease: study design of a randomized clinical trial. BMC Neurol. 2013; 13: 137, doi: 10.1186/1471-2377-13-137.
27. Barnes G.R., Hillebrand A. Statistical flattening of MEG beamformer images. Hum. Brain Mapp. 2003; 18(1): 1–12, doi: 10.1002/hbm.10072.
28. Hong S.H., Im S., Park G.Y. The effects of visual and haptic vertical stimulation on standing balance in stroke patients. Ann. Rehabil. Med. 2013; 37(6): 862–870, doi: 10.5535/arm.2013.37.6.862.
29. Halmi Z., Stone T.W., Dinya E., Mally J. Postural instability years after stroke. J. Stroke Cerebrovasc. Dis. 2020; 29(9): 105038.
30. Fedak D., Latała B., Otfinowski J., Zajdel K. Ocena wpływu fizjoterapii na równowagę w pozycji stojącej w grupie pacjentów po udarze mózgu określona na podstawie badań posturograficznych. Acta Bio-Opt. Inform. Med. 2010; 16(3): 208–211.
31. Zajdel K., Latała B., Mosurska D. Użyteczność posturografii i prób kalorycznych w wybranych schorzeniach neurologicznych. Prz. Lek. 2009; 66(11): 920–923.
32. Song Y.B., Chun M.H., Kim W., Lee S.J., Yi J.H., Park D.H. The effect of virtual reality and tetra-ataxiometric posturography programs on stroke patients with impaired standing balance. Ann. Rehabil. Med. 2014; 38(2): 160–166, doi: 10.5535/arm.2014.38.2.160.
33. Ho T.H., Yang F.C., Lin R.C., Chien W.C., Chung C.H., Chiang S.L. et al. Impact of virtual reality-based rehabilitation on functional outcomes in patients with acute stroke: a retrospective case-matched study. J. Neurol. 2019; 266(3): 589–597, doi: 10.1007/s00415-018-09171-2.
34. Kılınç M., Avcu F., Onursal O., Ayvat E., Demirci C.S., Yildirim S.A. The effects of Bobath-based trunk exercises on trunk control, functional capacity, balance, and gait: a pilot randomized controlled trial. Top. Stroke Rehabil. 2016; 23(1): 50–58, doi: 10.1179/1945511915Y.0000000011.
35. Lu R.R., Li F., Wu Y., Hu Y.S., Xu X.L., Zou R.L. et al. Demonstration of posturographic parameters of squat-stand activity in hemiparetic patients on a new multi-utility balance assessing and training system. J. Neuroeng. Rehabil. 2013; 10: 37, doi: 10.1186/1743-0003-10-37.