Innovative System for Evaluation and Rehabilitation of Human Imbalance

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ABSTRACT:

Introduction: Mobile posturography is based on wearable inertial sensors; it allows to test static stability (static posturography) and gait disturbances.

Aim: The aim of this work was to present the results of research on the innovative MEDIPOST system used for diagnosis and rehabilitation of balance disorders.

Material and methods: Fourteen articles published in influenced foreign journals were presented and discussed. The development and construction of the device was preceded by a literature review and methodological work. The Dizziness Handicap Inventory (DHI) questionnaire was translated and validated. The methodology of posturography with head movements with a frequency of 0.3 Hz was also developed in the group with chronic vestibular disorders. Simultaneous measurements were performed (static posturography vs. MEDIPOST) in the CTSIB-M (Modified Clinical Test of Sensory Interaction in Balance) test in healthy subjects and patients with unilateral peripheral dysfunction.

Results: In the posturography with head movements the improvement of sensitivity (67 to 74%) and specificity (65 to 71%) was noted. In the CTSIB-M test the intraclass correlation coefficients for both methods were 0.9. The greatest differences between examinations were observed for the mean angular velocity in the tests on the foam (trials no. 3 and 4), in particular on the foam with eyes closed (trial no. 4 – sensitivity 86.4%, specificity 87.7%). Two functional tests were analyzed: the Swap Seats test and the 360 degree turn test. In the former, the results are studied from 6 sensors – 86% of the true positives and 73% of the true negatives for the fall/ no-fall group classification. The second test differentiates people with vestibular impairment and healthy people. It can be analyzed with 1 (sensitivity 80%) and 6 sensors (sensitivity 86%, specificity 84%). Currently, the MEDIPOST device is in the development and certification phase.

KEYWORDS: balance dysfunction, dizziness, mobile posturography, vertigo, vestibular rehabilitation

ABBREVIATIONS

APTA – American Physical Therapy Association
BBS – Berg Balance Scale
COM – center of body mass
CTSIB-M – Modified Clinical Test of Sensory Interaction on Balance
DGI – Dynamic Gait Index
DHI – Dizziness Handicap Inventory
IF – Impact Factor
ROC – Receiver Operating Characteristic
SM – sclerosis multiplex
SOT – Sensory Organization Test
TUG – Timed Up and Go Test
VSS-sf – Vertigo Symptom Scale-short form

Innovative, easy-to-use MEDIPOST devices for diagnosis of balance disorders were constructed. MEDIPOST permits the examination of static stability (static posturography), as well as gait disorders (mobile posturography), thus allowing to assess the performance of the balance system in the conditions of daily life. The project was carried out as part of a grant from the National Center for Research and Development entitled “Innovative system for evaluation and rehabilitation of human balance” (“Prevention and treatment of civilization diseases” program, STRATEGMED 2/266299/19NCBR/2016). The project was implemented by a consortium led by the Lodz University of Technology and members of the Medical University of Lodz, the Institute of Occupational Medicine in Lodz, Labo Clinic Sp. z o.o and Platinum Seed Incubator Sp. z o.o. One project indicator was the publication of papers presenting the research results in journals with a high Impact Factor.

The papers were published in foreign journals; therefore, they are not widely recognized in Poland, which is why we will present and discuss the most important of them. So far, 14 papers with a total IF 43.2 [1–14] have been published, and more are prepared for publication [15].
Mobile posturography is applicable to the rehabilitation of balance disorders and the assessment of the risk of falls in elderly patients. The advantage of such devices is a small size, multifunctionality, mobility, and low cost compared to classical posturography. Objective information (a record of wobbling or gait) is provided during tests which involve elements characteristic of daily activity. Another application of these devices is the rehabilitation of balance disorders in labyrinthine disorder or in neurological diseases, most often in patients with Parkinson's disease, multiple sclerosis or musculoskeletal disorders.

The project aimed to develop a device comparable to the costly static posturography, which requires considerable space.

The development and construction of the MEDIPOST device was preceded by a literature review [1], which aimed to summarize the current knowledge on the use of mobile posturography in the diagnosis and rehabilitation of patients with vertigo and balance disorders. We searched the PubMed (Medline) and Embase (OVID) databases using the following keywords: “mobile posturography”, “wearable sensors”, “mobile devices”, “clinical tests with sensors”. The following device parameters were analyzed: type, location, number of sensors, data acquisition systems. The applicability of these mobile devices to clinical balance assessment protocols was verified. The possibilities of using mobile devices, including smartphones with appropriate applications installed, to recognize falls in the elderly group and in the rehabilitation of balance disorders, were presented. More detailed information can be found in the study by Gawronska et al. [1].

The design of the MEDIPOST apparatus involves two versions: basic (1 sensor) with an attachment point on the fourth lumbar vertebra – since it is assumed that the center of body mass (COM) is located at this height. This variant provides information comparable to static posturography (Fig. 1.).

The extended version (6 sensors) with sensors mounted on the extremities (thighs and lower legs as well as in the cervicothoracic junction) records gait and other types of movement (mobile posturography) (Fig. 2.).

The development of the MEDIPOST apparatus was preceded by methodological works, which involved translation and validation of the Dizziness Handicap Inventory (DHI) [2] and the assessment of its usefulness in various groups of patients with vertigo and balance disorders [3]. We also developed a protocol of posturography with head movements of 0.3 Hz, which recognized head movements as a trigger for imbalances in individuals with uncompensated vestibular injury [4, 5]. Tests on the posturographic platform revealed an improvement in sensitivity (from 67 to 74%) and specificity (from 65 to 71%) in the group with chronic vertigo after adding head movements compared to a standard posturographic test [4]. Based on the research carried out, posturography with head movement should be included in the test panel for mobile posturography. Normative values in a group of healthy people were developed for the MEDIPOST apparatus. Next, studies were carried out in a group of patients with dizziness and balance disorders who had uncompensated unilateral vestibular dysfunction (asymmetry of vestibular caloric response ≥30%). Analysis of the ROC (Receiver Operating Characteristic) curve allowed to determine cut-off points with a maximum sensitivity of 87% and specificity of 96% for trial no. 4 on the foam with eyes closed [5].

One stage of validation of the new device involved simultaneous measurements using mobile posturography MEDIPOST and static posturography in the CTSIB-M (Modified Clinical Test of Sensory Interaction on Balance) performed in healthy subjects and patients with unilateral peripheral vestibular dysfunction. The intraclass correlation coefficients obtained for both methods were 0.9, which should be interpreted as perfect agreement, despite significant differences in the measurement principle [6]. The largest gender disproportions were observed for the mean angular velocity of the center of gravity in the tests on the foam (trials no. 3 and 4), and in particular in the tests performed on the foam with eyes closed (trial no. 4). Trial no. 4 also showed the best ability to discriminate between healthy people and patients with unilateral peripheral vestibular dysfunction (sensitivity 86.4%, specificity 87.7%). Both methods showed no statistically significant difference compared to the ROC curves [7].

Static posturography (CTSIB-M) tests and the equivalent of this protocol with head movements were also supplemented with the development of a number of functional tests for MEDIPOST. Two of these tests were analyzed in detail, i.e., “Swap Seats” and the 360 degree turn test. The former is useful for assessing the risk of falls in people with vestibular dysfunction. This test is originally derived from the Berg Balance Scale; however, the assessment of the results involves taking readings from individual 6 sensors, which are then analyzed by means of neural networks. In studies conducted in the group of healthy people and patients with vestibular dysfunction, the Swap Seats test showed 86% true positives and 73% true negative results for the fall/no-fall group classification (the Dynamic Posturography Sensory Organization Test; SOT was used as the reference study) [8]. The 360 degree turn test was used to differentiate
TUG test. The test tools usually involve a stopwatch or a ruler. We developed a 13-point protocol for the functional assessment of balance and gait disorders for the MEDIPOST apparatus. The protocol involves scale points: Berg, Dynamic Gait Index (DGI) and elements of the TUG test, which reveal balance disorders. The device enables a quantitative analysis of the test parameters, which is meaningful in monitoring rehabilitation.

Rehabilitation protocols based on data from MEDIPOST [10–13] were prepared for the project. Moreover, a tool for rehabilitation with the use of virtual reality, recommended in 2021 by the American Physical Therapy Association (APTA – the most important American society associating over 100.000 rehabilitation and physical therapy specialists), was developed [16]. The authors of the guidelines emphasize that rehabilitation that uses non-immersive virtual reality programs are as valuable as the programs used so far. In addition, the inclusion thereof may be associated with greater compliance by patients, and the use of immersion therapy may entail better functional outcomes of therapy. The scientific evidence underlying this recommendation includes the work of Rosiak et al., which is discussed and quoted on several occasions, thus making a critical contribution to the development of rehabilitation in people with vertigo [12, 13].

The paper prepared for publication compared the results of mobile posturography with clinical tests and the patient’s self-assessment to examine the effectiveness of rehabilitation in patients with balance disorders. The patients completed the Dizziness Handicap Inventory (DHI) and the Vertigo Symptom Scale-short form (VSSsf). The clinical tests performed involved Tinetti Gait and Balance Assessment, Timed Up and Go Test (TUG), Berg Balance Scale (BBS), and Dynamic Gait Index (DGI). There was a reduction in symptoms after rehabilitation, and the results of MEDIPOST mobile posturography were much better correlated with it than those of clinical functional tests.

The rehabilitation protocol developed during the project was also used in a patient with a unique course of neuroborreliosis, manifested mainly as a feeling of instability, significant gait disturbances, and dizziness. Rehabilitation was successfully applied as an adjunct to pharmacotherapy and a significant improvement in the patient’s stability was achieved [14].

Currently, the project results are in the development and certification phase. Further research directions include, in particular, the evaluation of functional tests in disease entities other than vestibular dysfunction. Literature data indicate the usefulness of mobile posturography in diseases where balance and gait disturbances are one of the symptoms, e.g., in MS or Parkinson’s disease.

Functional assessment of the balance system consists in conducting tests that “simulate” the conditions of everyday life. Such tests allow to determine the “performance” of the balance system and facilitate preparing rehabilitation plans adapted to the detected deficits. The tests consist in motor or static tasks. The quality of performance of these tasks is assessed by the therapist, who usually gives points, e.g., the Tinetti test, or measures the execution time of the task, as in the TUG test. The test tools usually involve a stopwatch or a ruler. We developed a 13-point protocol for the functional assessment of balance and gait disorders for the MEDIPOST apparatus. The protocol involves scale points: Berg, Dynamic Gait Index (DGI) and elements of the TUG test, which reveal balance disorders. The device enables a quantitative analysis of the test parameters, which is meaningful in monitoring rehabilitation.

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REFERENCES

Fig. 2. MEDIPOST device – 6-sensor variant.
Table of content: https://otolaryngologypl.com/issue/14605

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Competing interests: The authors declare that they have no competing interests.

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