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Review article

Balance evaluation techniques and physical therapy in post-stroke patients: A literature review

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A B S T R A C T

A stroke (cerebrovascular accident – CVA) is a significant social–economic issue. Approximately 15–30% of all patients develop life-long disability, 20% require over 3 months of specialized care in healthcare institutions, and the majority of the patients never recover the ability to maintain a proper vertical position. Such CVA sequelae as balance disturbances not only negatively affect patients' daily physical activity, but also result in social isolation. A number of standardized clinical scales, tests, and instrumental examination techniques have been proposed for evaluating not only post-CVA balance function, but also any changes in this function following various interventions. Even though scientific literature lists numerous methods and instruments for the improvement of balance after a CVA, not all of them are equally effective, and there have been rather controversial evaluations of some techniques. Nevertheless, the application of the majority of the techniques as complementary or alternative measures to traditional physical therapy (PT) frequently yields better results.

1. Introduction

Balance impairment ranks first (ca. 87.5%) among post-CVA disorders [1]. Reduced muscle force and range of motion, impaired motor coordination, and sensory organization issues emerging after a stroke (CVA) impair the maintenance of balance [2]. Impaired balance not only increases the risk of falls and social isolation, but also negatively affects physical activity [3].

According to the data of the World Health Organization (WHO), approximately 15 million people worldwide experience CVA. Of these, nearly 5 million die, 5 million has been recovered and another 5 million develop permanent disability [4]. CVA ranks third among the most common causes of death in the United States, and second – in other developed countries [5]. In Lithuania, the prevalence of CVA remains high, and CVA-associated mortality is increasing with every year [6].

2. A stroke and its associated symptoms

Motor disorders are the most common (80–90%) clinical signs of CVA. They are the main disability-causing factors [7]. Two

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thirds of patients experience hemiparesis. Monoplegia occurs in 19% of CVA patients – usually secondary to small cortical infarctions in the motor area or the white matter (centrum semiovale) [8].

Balance impairment ranks first (ca. 87.5% of cases) among CVA-related disorders [1,9]. Stroke survivors typically have decelerated and impaired balance reactions, poorer body weight support on the affected limb, and excessive postural sway [10,11]. Instability in stationary positions was observed twice as often as in healthy individuals of the same age group [12].

Movement disorders are not common after a CVA. They may emerge immediately after a stroke or later, but they usually resolve after some time [13]. Most commonly, the following movement disorders are observed: dystonia, chorea with or without hemiballismus, tremors, parkinsonism, athetosis, pseudoathetosis, and asterixis [13,14]. Dyskinesia may be unilateral, bilateral, focal (when a single body part is affected), or segmented (when the abnormality is observed in several adjacent body parts) [14]. Movement disorders are more associated with hemorrhagic rather than with ischemic CVA [13].

Sensory impairment is seen in about 50% of CVA patients. A cortical stroke usually results in sensory discrimination impairment with relatively intact simple sensations (''protopathic sensations''). Sometimes this impairment may be accompanied by such neurological disorders as hemianopsia, aphasia or hemispatial neglect. In over 50% of cases, sensory disorders include the face, the arm, the trunk, and the leg of the affected side. Frequently, the ''pusher syndrome'' occurs in the posterior thalamus of stroke survivors. In case of the infarction of the artery of Percheron (thalamo-subthalamic paramedian artery), 75% of patients experience sensory deficit with concomitant vision disorders (73%) and cognitive behavioral disorders (43%) [8].

Up to 64% of stroke survivors have cognitive function disorders of varying degrees [15]. If a CVA occurs in the left hemisphere, the following cognitive disorders are usually observed: apraxia, aphasia, dyscalculia, amnesia, and emotionality frequently manifested through excessive irritability and inadequate reactions [16].

CVA occurring in the right hemisphere may result in difficulty locating objects, ascending and descending the stairs, and dressing oneself because this side of the brain is responsible for visual-spatial functions such as determining the size, position, and speed of objects, evaluation of distances, etc. [16].

The body's ability to maintain balance – i.e. maintaining the body center of mass within the base of support – is continuously regulated by the higher nerve centers through the reception, purposeful integration, and regulation of external impulses [17]. Information received from sensory systems is synthesized in the central nervous system (CNS) based on the internal schematic models of the body, and then a respective body response is formed through the activation of position-maintaining muscle synergies ensuring the corresponding movements of the head, eyes, trunk, and limbs, thus ensuring the maintenance of balance [18].

Two types of balance are identified – the *static* and the *dynamic* ones. The maintenance of the body position, or balance, may be defined statically – i.e. as the ability to maintain the position with respect to the base of support during minimal movement, and dynamically – i.e. as the ability to perform a specific task while maintaining a stable position [19]. Mancini and Horak identified the following functional goals of the balance system [18]:

1. Maintenance of a specific postural alignment, such as sitting or standing;
2. Facilitation of voluntary movement, such as the movement transitions between postures; and
3. Reactions that recover equilibrium to external disturbances, such as a trip, slip, or push.

3. Balance control and influencing factors

Balance control is a complex process involving the maintenance of posture, the facilitation of movement, and the recovery of balance. Balance is maintained via a complex integration and coordination of multiple body systems, including the vestibular system, vision, hearing, and motor and higher-order premotor systems [18]. To maintain the vertical position of the body, the central and the peripheral components of the nervous system continuously interact, controlling the positioning of body parts and the body center of mass with respect to its base of support.

Weight bearing on the paretic lower extremity and transfer of weight from one lower extremity to the other are important goals of stroke rehabilitation [20].

Ahmet İnanir et al. evaluated the effectiveness of Conventional Rehabilitation Therapy on Postural Stability and Clinic in Stroke Patients with Hemiplegia. The evaluation showed that this approach is effective and useful in restoring static and dynamic balance as well as in obtaining an effective improvement in the treatment of patients with stroke through conventional treatment [21].

Oliveira et al. identified the following mechanisms associated with balance control [22]:

- Sensory processes and their integration (sensory afferents);
- Biomechanical constraints;
- Movement strategies;
- Cognitive processing;
- Perception of verticality.

Sensory processes and their integration: There are three main sensory mechanisms participating in the control of the body position: the somatosensory mechanism (the proprioceptive system, which provides information about the position of different body parts with respect to each other), the visual mechanism (defines the position and the movements of the head with respect to the surrounding objects), and the vestibular system (defines the direction and the acceleration of body movements with respect to the gravity of the Earth) [22,23]. The sensory information is regulated dynamically and changes depending on the altering environmental conditions [23]. Petarka stated that, despite multiple possible sensory sources, the CNS prefers one system to another in order to keep balance in the vertical position [23]. This ability to select and use respective sensory contributions in different environmental conditions is called sensory reweighting [22,24]. For instance, when standing on an unstable surface, the CNS increases sensitivity to sensory feedback received from vision and the vestibular system, reducing sensitivity to information received from the somatosensory system. Meanwhile, in darkness, balance control mostly depends on the feedback from the somatosensory system and the vestibular system [22].

Biomechanical constraints: Control of the body center of mass with respect to its base of support is one of the major factors in balance control [24]. The base of support is not fixed and may vary depending on the task, the movement, individual biomechanics, and environmental factors. Any impairment in muscle force, range of motion, tone, or muscle control will affect the maintenance of balance [22].

When standing, the limits of stability are the area in which the individual may shift his or her body center of mass and yet maintain balance without changing the borders of the base of support. This base resembles a cone in its shape. Thus, balance is not merely some fixed position, but also includes a certain area that is defined not only by the size of the base of support, but also by an individual's range of motion, muscle force, and sensory feedback [24].

Movement strategies: There are three main movement strategies that can be used to restore balance in the body – *ankle, hip*, and *stepping* [22,24,25]. These compensatory strategies are significantly faster than voluntary limb movements, and are useful for reducing oscillations of the body center of mass resulting from abrupt and unexpected balance impairment [25]. These strategies include certain muscle synergies, movement models, joint rotation momenta, and vertical forces against the base of support [22].

The ankle strategy is applied for balance maintenance in cases where sway is relatively mild, and the base of support is firm. *The hip* strategy is used in the presence of greater or faster disturbances or when the base of support is narrow or sloping, and the ankle strategy is insufficient for regaining balance, while the center of mass has to be restored quickly *The stepping strategy* is an entirely independent strategy. When using this strategy, the adjustment to the base of support is achieved through shifting the body center of mass – differently to the other two strategies [22,24].

Cognitive processing: Motor responses and activation of muscle synergies for the maintenance of balance are influenced by sensory feedback, and are also dependent on attention (focus), experience, the environmental contexts, and the intentions [22]. The importance of cognitive processing directly correlates with the difficulty level of the posture-related task that needs to be performed. Patients whose cognitive processing is impaired due to neurological disorders may need more cognitive resources for maintaining balance [24]. Post-stroke patients may need more focusing efforts when performing tasks that require static posture control – especially with increasing complexity of the tasks. Insufficient distribution of attention may increase the risk of instability and the probability of falls [22].

Perception of verticality: Spatial orientation with respect to gravity forces is essential in maintaining vertical position of the body when walking or performing various motor tasks. Damage to the central system integrating vestibular, somatosensory, and visual information or to the central or peripheral vestibular systems may disturb the normal perception of the position of the body in space, and may affect certain mechanisms responsible for the perception of the verticality of the body [26]. Frequently, post-stroke patients with balance disorders avoid shifting their weight on the unaffected side. This phenomenon is frequently referred to as the pusher syndrome. Its clinical manifestation is the tendency to shift the body weight more to the paretic side for fear of falling on the unaffected side. Such cases demonstrate impaired perception of the body's verticality relative to the gravito-inertial force [22]. The patients perceive the position of their body as straight, while in reality their body is leaning toward the paretic side [22,24]. It is interesting to note that such patients have no impairment in the processing of visual and vestibular feedback responsible for the visual perception of verticality [22].

4. Balance evaluation techniques in post-stroke patients

4.1. *Clinical scales and tests*

Various techniques are applied for the evaluation of balance in post-stroke patients [2]. Static balance tests are used for the evaluation of patients' ability to maintain their body center of mass within its base of support when remaining in a stable position. Dynamic tests are applied for the evaluation of balance during voluntary movements or under external disturbances. During functional balance tests, the subjects have to maintain balance when performing tasks of various complexity – e.g. when rotating, sitting, shifting from the sitting to the standing position, standing in various positions, walking, etc. [22]. In functional balance tests, task performance is usually evaluated on 3–5 point scales or by evaluating the time during which the subject managed to maintain the required position. The tests are used to evaluate the balance function and its changes following the intervention [18].

Literature sources present multiple standardized scales and tests for the evaluation of balance in post-CVA patients. Most commonly, the following scales and tests are used: the Berg Balance Scale, the Timed Up and Go Test, the Tineti Assessment Tool, the Functional Reach Test, the balance subscale of the Fugl-Meyer Assessment, the Postural Assessment Scale for Stroke Patients (PASS), the Dynamic Gait Index, the Multidirectional Reach Test, the Activities-Specific Balance Confidence Scale, and the Fullerton Advanced Balance Scale [11,22,27].

Even though these tests and scales do not require expensive equipment and are relatively fast, yet the results are subjective and have the characteristic ceiling effect, and thus these techniques are insufficiently sensitive for the detection and evaluation of slight balance-related alterations. According to Mancini and Horak, these instruments are too simple to evaluate the complex system of balance control, and the objectiveness of the results may vary significantly depending on the impartiality level of the researcher [18].

The optimal balance evaluation technique should include objective and quantitative measurements that would provide detailed, easily comprehensible, and reliable findings. For this reason, the application of computer technologies is becoming increasingly common in clinical practice for an objective evaluation of balance and its influencing mechanisms [18].

4.2. *Instrumental studies*

Laboratory measurements are significantly more sensitive in the evaluation of balance than clinical scales are. *Posturography* is one of the most common laboratory techniques used for balance evaluation [2]. Quantitative posturography employs force platforms for the determination of the movement trajectory of the center of pressure. The trajectory of the variations on the center of pressure reflects body sway and the ability of the nervous and the musculoskeletal systems to integrate feedback from various sensory systems including vision and somatosensory and vestibular systems, which are related to the maintenance of balance [11].

During posturography, information about body sway from the sensors in the force platforms is relayed to the computer, and oscillation curves – posturograms – are recorded. The posturograms indicate the range of sagittal and transverse sway, the length of the movement trajectory of the center of pressure, and the frequency of the oscillations. Posturography is differentiated into two techniques – *static* and *dynamic* posturography. Static posturography evaluates the subjects' ability to maintain balance while standing still and without any external disturbances. Dynamic posturography evaluates the subjects' ability to maintain balance while being exposed to various external stimuli that may result either from the movement of the base of support, the subject, or a direct interference from another person – e.g. by gently pushing the subject [28].

During static or dynamic posturography, changing various sensory conditions – i.e. the elimination or manipulation of various stimuli allows for determining how the subjects' maintenance of balance depends on the visual, proprioceptive, and vestibular feedback [18].

Accelerometry is one of the most recent balance evaluation techniques. Even though it was first proposed back in 1970, it was only during the last 10–15 years that this technique was improved and prepared for use in clinical practice. This technique is related to posturography, but it does not require laboratory settings.

Accelerometers are instruments that measure motion velocity and acceleration of the body parts in three axes – the vertical, the horizontal, and the transverse ones [29]. These devices are attached to the subject's trunk and limbs, and computer equipment is used to analyze the incoming signals [30]. The measurements may be carried out while the subject is performing balance tests or is engaging in daily activities [18].

Accelerometry helps to evaluate movements, balance and its alterations, energy consumption, and the speed and intensity of movement [29]. The greatest advantage of accelerometers is that they are portable and easy to use – differently from posturography, which requires force platforms. This makes accelerometry a cheaper option [28].

The aim of a study by Lemmens et al. was to assess the extent to which accelerometers can be used to determine the effect of robot-supported task-oriented arm-hand training, relative to task-oriented arm-hand training alone, on the actual amount of arm-hand use among chronic stroke patients in their home settings. After the evaluation, the researchers concluded that accelerometer data did not show any significant changes in the actual amount of arm-hand use after task-oriented training with or without robot support. In addition to the amount of use, discrimination between the activities performed and information about the quality of use of the affected arm-hand are essential to determine the actual arm-hand performance [31].

The aim of a study by Marika Noorkõiv et al. was to identify and summarize publications that reported clinical applications of upper limb accelerometry for stroke within free-living environments and to make recommendations for future studies. The quality of the study is reflected by the number of the participants, the methodological approach, technical details of the equipment used, blinding of clinical measures, and the collection of safety and compliance data. The correlation between clinical assessments and accelerometry was tested in five studies, and significant correlations were found. Three studies assessed the efficacy of a rehabilitation intervention using accelerometry: in two studies, both accelerometry and clinical test scores detected a post-treatment difference, but in one study, accelerometry data did not change despite clinical test scores showing motor and functional improvements. Further research is needed to understand the additional value of accelerometry as a measure of upper limb use and function in the clinical context. A simple and easily interpretable accelerometry approach is required [32].

5. Balance training techniques in post-stroke patients

Scientific literature provides a number of methods and instruments for balance training after a CVA. Not all of them are always considered to be effective – there are controversial evaluations as well. Nevertheless, the application of the majority of the techniques as complementary or alternative measures to traditional physical therapy (PT) frequently helps to achieve better results.

Dual-task training is a technique that is frequently mentioned in scientific literature [33–35]. This is simultaneous performance of two tasks. During balance training, while maintaining body position, another task – usually of motor or cognitive character – is performed [33,34].

Her and coauthors conducted a study with stroke survivors. The subjects were distributed into three groups. One group of subjects underwent balance training by performing dual motor tasks (bouncing a ball against the ground, holding a glass with water, etc. while standing on an unstable surface); the second group performed dual tasks of cognitive character (counting backwards, doing mental calculations, etc., while standing on an unstable surface), and the third group performed dual tasks of motor-cognitive character (bouncing a ball against the ground and counting backwards, etc., while standing on an unstable surface). The results of the intervention showed that oscillations of the center of mass statistically significantly decreased in all three groups. The results of balance evaluation using the Berg Balance Scale and the evaluation of daily activity using the Functional Independence Measure showed a statistically significant improvement in balance and daily activity scores in all subject groups after the intervention. The comparison of the results between the groups showed that the results in the third group were statistically significantly better than those of the other two groups [33].

Jiejiavo and coauthors also conducted a study in order to evaluate the effectiveness of balance training using dual cognitive tasks. The results after an 8-week-long intervention showed that static balance (lateral body sway with eyes closed or open and sagittal sway with eyes open) was statistically significantly better after balance training by applying dual cognitive-type tasks than after standard PT [34].

Posture control depends on the somatosensory information received from the feet pressing against the support surface. Standing on an unstable surface causes an increased external body sway, which stimulates posture coordination – i.e. the sensory and the motor systems are stimulated to adapt rapidly. When maintaining balance on an unstable surface, stimulation of the muscle spindle receptors through gamma motor neurons occurs, thus ensuring motor response – which, in turn, affects joint stability [36].

Lee and coauthors conducted a study to compare the effectiveness of balance training in post-CVA patients on stable and unstable surfaces. The results obtained after six weeks of intervention showed that balance training on unstable surfaces yielded significantly better results [36].

Onigbind and colleagues conducted a study where they applied standard PT or PT on unstable surfaces for balance training. The researchers noticed that the use of unstable surfaces was more efficient for restoring the balance function. Statistically significant changes were registered after the intervention when evaluating dynamic balance and static balance with eyes closed, yet no significant changes were observed in the evaluation of static balance with eyes open [37].

Control of the trunk movements is highly important for maintaining balance [38,39]; control of the trunk determines the ability to stand, weight shifting, and the performance of selective torso movements while maintaining the body center of mass within the limits of the base of support in conditions demanding both dynamic and static balance [38]. The aim of the study conducted by Karthikbabu and coauthors was to evaluate how trunk exercises performed on an unstable surface (an exercise ball) or on a stable surface affect trunk control and balance in post-CVA patients in an acute phase of the disease. The subjects were randomized into two groups. In addition to the standard PT applied to both groups, the experimental group additionally performed trunk exercises on an exercise ball, whereas the control group exercised on mats. The evaluation of the results after the intervention showed an improvement in trunk control in both groups of patients, yet the use of an exercise ball yielded better results [38].

Ki Hun Cho and Wan Hee Lee evaluated the effect of treadmill training-based real-world video recording on balance and gait in chronic stroke patients. The findings of this study demonstrated that the real-world video recording had an effect on dynamic balance and gait in chronic stroke patients when added to treadmill walking [40].

Balance training by applying visual and auditory feedback is considered an effective technique for the improvement of balance control [10,41,42]. The use of additional visual information in post-CVA patients is believed to improve their perception of the actual body position and shift in space [10,43], as well as weight distribution and static and dynamic stability [44].

Balance training on force platforms with visual feedback provides the patients with real-time information on the current position of their body and the body center of mass, which helps the patients to ensure better control and maintenance of a certain posture when changing body position [41,42].

Srivastava and colleagues conducted a study where they evaluated the effectiveness of balance training on the patients' functional skills when using force platforms with visual feedback in patients who had experienced CVA three months before. The results of the study showed that in patients who experienced balance and gait disturbances after a CVA, a 4-week balance training program on force platforms with visual feedback significantly improved balance control and functional skills immediately after the intervention and three months later [42].

Lee and colleagues conducted a study where they evaluated the influence of visual feedback on the improvement of post-CVA patients' ability to maintain sitting balance. The evaluation of the results after the intervention showed a statistically significant improvement in both static and dynamic balance in the sitting position in subjects who in addition to the standard PT underwent balance training by using visual feedback [41].

Video games as a rehabilitation technique in physical therapy attracted significant attention during the last few years. Case–control studies conducted in this field have shown that the use of video games in rehabilitation is an effective technique in balance training [43,45,46].

Cho and colleagues in their study evaluated the effect of a 6-week rehabilitation program with virtual reality games on static and dynamic balance in post-CVA patients. The study showed that additional balance training with the use of video games significantly improved dynamic balance, compared to standard PT, but no statistically significant difference was observed in case of static balance [46].

A study by Morone et al. evaluated the effect of video game-based rehabilitation on balance and functional recovery in post-CVA patients during the subacute period. The study showed that subjects who received additional video game-based intervention showed a significant improvement in their balance function and a reduction in dependence in their daily activities, compared to patients who received standard PT alone [45].

Llorens and colleagues in their study evaluated the effectiveness and the usability of a virtual reality-based intervention compared with conventional physical therapy in balance recovery among individuals with chronic stroke. Balance performance was assessed at the beginning and at the end of the trial using the Berg Balance Scale, the balance and gait subscales of the Tinetti Performance-Oriented Mobility

Assessment, the Brunel Balance Assessment, and the 10-m Walking Test. Subjective data of the virtual reality-based intervention were collected from the experimental group, with a feedback questionnaire used at the end of the trial. Virtual reality interventions can be an effective resource to enhance the improvement of balance in individuals with chronic stroke [47]. In other study Llorens and colleagues evaluated the clinical effectiveness of a virtual reality (VR)-based telerehabilitation program in the balance recovery of individuals with hemiparesis after stroke in comparison with an in-clinic program; second, to compare the subjective experiences; and third, to contrast the costs of both programs. They involve in the study outpatients with stroke ($N = 30$) with residual hemiparesis and aply intervention twenty 45-minute training sessions with the telerehabilitation system, conducted 3 times a week, in the clinic or in the home. Main results they have are First, VR-based telerehabilitation interventions can promote the reacquisition of locomotor skills associated with balance in the same way as do in-clinic interventions, both complemented with a conventional therapy program; second, the usability of and motivation to use the 2 interventions can be similar; and third, telerehabilitation interventions can involve savings that vary depending on each scenario [48].

Bauer P and colleagues in their study investigated whether functional electrical stimulation (FES)-assisted active cycling was more effective in improving walking and balance than active cycling without FES was. After the intervention, the authors concluded that FES-assisted active cycling seemed to be a promising intervention during rehabilitation in patients with stroke [49].

After the evaluation of the effectiveness of virtual reality-enhanced body weight-supported treadmill training on lower limb motor function in subacute cerebral infarction patients, Xiao and colleagues claimed that the training improved stroke patients' walking function. Virtual reality-enhanced body weight-supported treadmill training has been proposed as a strategy for gait training in post-cerebral infarction subjects [50].

The aim of the study by YoungJun Ko et al. [51] was to determine the effects of balance training with Space Balance 3D, which is a computerized measurement and visual feedback balance assessment system, on balance and mobility in acute stroke patients. This was a randomized controlled trial in which 52 subjects were assigned randomly to either the experimental group or the control group. The experimental group, which contained 26 subjects, underwent balance training with a Space Balance 3D exercise program on top of conventional physical therapy interventions 5 times per week during 3 weeks. After the evaluation, the authors argued that The Space Balance 3D training with conventional physical therapy intervention should be recommended for the improvement of balance and mobility in acute stroke patients [52].

Scientific literature provides research data indicating that balance training on a stationary bicycle is a useful technique for the restoration of the balance function after a CVA [53].

A positive effect was also observed when using a treadmill for balance training [54–56]. A study of Lau et al. showed that the speed of the treadmill (constant or varying) had no significant effect on balance training, but changing treadmill speed yielded better results in the evaluation of the speed of gait and the length of the step [56]. Studies conducted by Kag et al. and Yang et al. showed that treadmill exercises with additional visual information yielded better results in balance training than treadmill exercises alone [54,55].

Various exercises and tasks for weight-shift training, sit-to-stand training, and reaching tasks are frequently applied for balance training in post-CVA patients [57–59].

Recently there has been a rise in the interest in the usefulness of exercises in water for the rehabilitation of post-CVA patients. Most studies comparing the effectiveness of balance training in the water and in a gym showed that better results were achieved during balance training in water [54,60–63].

There is an opinion that body sway, which is a characteristic consequence of CVA, psychologically increases stroke patients' fear of falling, thus limiting the effectiveness of balance training. Meanwhile, when exercising in water, its physical characteristics (hydrostatic pressure, the lift force, and high density) reduce the patients' fear of falls and injuries [60,61]. Water has a specific mechanical effect on the body, reducing pain, peripheral edemas, the activity of the sympathetic nervous system, and biomechanical muscle and joint tension, and improving proprioception, which creates better conditions for rehabilitation [60,63]

The results of the studies conducted by Kog Noh et al., Han et al., Lee et al., and Jung et al. evaluating the effectiveness of balance training in water and in a gym showed that balance training in water was more effective, and the difference, compared to balance training in a gym, was statistically significant [54,60,62,63].

Studies have also showed that exercising in water also improves muscle force [54] and proprioception [62], and has a positive effect on the functional status [39].

6. Generalization

A stroke (CVA) is one of the most common causes of morbidity, long-term disability, and mortality worldwide. The clinical symptoms of CVA are highly individual, but balance disorders are among the most common ones.

The analysis of literature showed that a number of authors still use clinical scales and tests for the evaluation of CVA patients' static and dynamic balance in their studies. These instruments include the Berg Balance Scale, the Timed Up and Go Test, the Tineti Assessment Tool, the Functional Reach Test, the balance subscale of the Fugl-Meyer Assessment, the Postural Assessment Scale for Stroke Patients (PASS), the Dynamic Gait Index, the Multidirectional Reach Test, the Activities-Specific Balance Confidence Scale, and the Fullerton Advanced Balance Scale. These tests do not require any expensive equipment and are applicable in everyday clinical practice. However, from the scientific perspective, they are rather subjective and insufficiently sensitive. A breakthrough in this area was facilitated by information technologies with feedback, which are being rapidly implemented in clinical practice. One of such IT-based techniques is accelerometry. Accelerometry is one of the most recent alternative techniques for the investigation and evaluation of balance, and is related to posturography, but does not require laboratory conditions or expensive equipment. During accelerometry, movements of the head with relation to the trunk are recorded even before changes in the position of the body mass center measured with the force platform occur. Thus, in practice, we already have a sufficiently sensitive and inexpensive instrument – an accelerometer, which could be used in research studies on balance evaluation.

Literature sources list a variety of balance restoration techniques. The main conclusions of the available research state that physical therapy in the water is more effective in restoring CVA patients' balance compared to physical therapy in the gym, while modern computer (video) technologies with feedback are significantly more effective for balance improvement, compared to the conventional balance control and functional recovery techniques. Besides, they are also significantly more attractive to the patients.

Balance disorders not only impair daily functional activity, but also limit both physical and social activity. This is the reason why the normalization and/or restoration of the impaired balance function has attracted such great attention, the efforts being focused not only on the search for the most objective and reliable clinical tests and instrumental research techniques for functional evaluation, but also on finding physical therapy techniques and equipment that would yield the best possible results.

Conflict of interest

None declared.

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Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; Uniform Requirements for manuscripts submitted to Biomedical journals.

REFERENCES

[1] Genthon N, Rougier P, Gissot AS, Froger J, Pélissier J, Pérennou D. Contribution of each lower limb to upright standing in stroke patients. J Am Heart Assoc 2008;39:1793–9.

[2] Oliveira CB, Medeiros RT, Greters MG, Conforto A. Abnormal sensory integration affects balance control in hemiparetic patients within the first year after stroke. Clinics 2011;66(12):2043–8.

[3] Michael K, Goldberg AP, Treuth MS, Beans J, Normandt P, Macko RF. Progressive adaptive physical activity in stroke improves balance, gait, and fitness: preliminary results. Top Stroke Rehabil 2009;16(2):133–9.

[4] Mandal A. Stroke epidemiology; 2014 [online]. Medical News. [cited 2014-11-27]. Available from internet http://www.news-medical.net/health/Stroke-Epidemiology.aspx.

[5] Gillen G. Stroke rehabilitation. A function-based approach. third edition. United States of America: Elsevier Mosby; 2011.

[6] Bižokaitė G, Daratienė J. Šilumos poveikis rankos spastiškumui sumažinti ergoterapijoje sergantiems galvos smegenų insultu [The effect of heat for reducing hand spasticity in post-stroke patients during occupational therapy]. Sveikatos mokslai 2011;1:3773–84.

[7] Bolognini N, Pascual-Leone A, Fregni F. Using non-invasive brain stimulation to augment motor training-induced plasticity. J Neuroeng Rehabil 2009;6(8):1–5.

[8] Ionita C. Stroke syndromes and their anatomic localization. Neurology MedLink; 2012 [online]. From Medscape Reference [cited 2013-03-12]. Available from the Internet http://www.medlink.com/CIP.ASP?UID=MLT002HH.

[9] Juocevičius I, Jamontaitė IE, Glamba V. Sergančiųjų galvos smegenų insultu pacientų funkcinės būklės pokyčiai ir jų prognozė antrajame reabilitacijos periode [Changes of functional status of patients after stroke during the second period of rehabilitation and prognosis of the results]. Gerontologija 2009;10(4):238–48.

[10] Yavuzer G, Eser F, Karakus D, Karaoglan B, Stam HJ. The effects of balance training on gait late after stroke: randomized controlled trial. Clin Rehabil 2006;20:960–96.

[11] Sawacha Z, Carraro E, Contessa P, Guiotto A, Masiero S, Cobelli C. Relationship between clinical and Instrumental balance assessments in chronic post-stroke hemiparesis subjects. J Neuroeng Rehabil 2013;10(95):1–7.

[12] Shin WS, Lee SW, Lee YW, Choi SB, Song CH. Effects of combined exercise training on balance of hemiplegic stroke patient. J Phys Ther Sci 2011;23:639–43.

[13] Bansil S, Prakash N, Kaye J, Wrigley S, Manata C, Stevens-Haas C, et al. Movement disorders after stroke in adults: a review. Tremor Other Hyperkinet Mov (NY) 2012;2:1–5.

[14] Handley A, Medcalf P, Hellier K, Dutta D. Movement disorder after stroke. Age Ageing 2009;38. 260–261, 265.

[15] Hachinski V, Iadecola C, Petersen RC, Breteler MM, Nyenhuis DL, Black SE, et al. National Institute of Neurological Disorders and Stroke – Canadian Stroke Network Vascular Cognitive Impairment Harmonization Standards. Stroke 2006;37:2220–41.

[16] Tan S. Right brain, left brain: memory and cognition after stroke. Neurology and Neurological Science; 2011 [online] From Stanford Hospital Health Library [cited 2014-03-09]. Available from the internet http://www.shlnews.org/?p=397.

[17] Seo K, Kim H, Han J. Effects of dual-task balance exercise on stroke patient's balance performance. J Phys Ther Sci 2012;24:593–5.

[18] Mancini M, Horak FB. The relevance of clinical balance assessment tools to differentiate balance deficits. Eur J Phys Rehabil Med 2010;46(2):239–48.

[19] Bressel E, Yonker JC, Kras J, Heath M. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. J Athl Train 2007;45(1):42–6.

[20] De Nunzio A, Zucchella C, Spicciato F, Tortola P, Vecchione C, Pierelli F, et al. Biofeedback rehabilitation of posture and weightbearing distribution in stroke: a center of foot pressure analysis. Funct Neurol 2014;29(2):127–34.

[21] İnanır A, Okan S, Filiz B, Kuyucu E. Effectiveness of conventional rehabilitation therapy on postural stability and clinic in stroke patients with hemiplegia. Cukurova Med J 2013;38(3):446–55.

[22] Oliveira CB, Medeiros RT, Frota NAF, Greters ME, Conforto AB. Balance control in hemiparetic stroke patients: main tools for evaluation. J Rehabil Res Dev 2008;45(8):1215–26.
[23] Peterka JR. Sensorimotor integration in human postural control. J Neurophysiol 2002;88(3):1097–118.
[24] Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing 2006;35(Suppl. 2):7–11.
[25] Maki BE, Macilroy WE. Control of rapid limb movement for balance recovery: age-related changes and implications for fall prevention. Age Ageing 2006;35(Suppl. 2):12–8.
[26] Mazibrada G, Tariq S, Pérennou D, Gresty M, Greenwood R, Bronstein AM. The peripheral nervous system and the perception of verticality. Gait Posture 2008;27(2):202–8.
[27] Ha H, Cho K, Lee W. Reliability of the good balance system® for postural sway measurement in poststroke patients. J Phys Ther Sci 2014;26:121–4.
[28] Dolinay J, Dolinay V, Vašek V, Dostálek P. Posturography device based on accelerometer. Int J Syst Appl Eng Develop 2014;8:155–62.
[29] Godfrey A, Conway R, Meagher D, OLaighin G. Direct measurement of human movement by accelerometry. Med Eng Phys 2008;30:1364–86.
[30] Kilikevičius A, Morkūnienė V, Višinskienė D. Žmogaus kūno stabilumo tyrimai [Human body stability investigation]. Sporto mokslas 2013;3(73):18–21.
[31] Lemmens RJ, Timmermans AA, Janssen-Potten YJ, Pulles SA, Geers RP, Bakx WG, et al. Accelerometry measuring the outcome of robot-supported upper limb training in chronic stroke: a randomized controlled trial. PLoS ONE 2014;9(5):e96414.
[32] Noorkõiv M, Rodgers H, Price I Ch. Accelerometer measurement of upper extremity movement after stroke: a systematic review of clinical studies. J Neuroeng Rehabil 2014;11:144.
[33] Her JG, Park KD, Yang YA, Ko T, Kim H, Lee J. Effects of balance training with various dual-task conditions on stroke patients. J Phys Ther Sci 2011;23:713–7.
[34] Jiejiao Z, Xueqiang W, Yueying X, Ying Y, Liyan S, Zhenwenet L. Cognitive dual-task training improves balance function in patients with stroke. HealthMED 2012;3(6):840–5.
[35] Kim GY, Han MR, Lee HG. Effect of dual-task rehabilitative training on cognitive and motor function of stroke patients. J Phys Ther Sci 2014;26:1–6.
[36] Lee JY, Park J, Lee D, Roh H. The effects of exercising on unstable surfaces on the balance ability of stroke patients. J Phys Ther Sci 2011;23:789–92.
[37] Onigbinde AT, Awotidebe T, Awosika H. Effect of 6 weeks wobble board exercises on static and dynamic balance of stroke survivors. Technol Health Care 2009;17:387–92.
[38] Karthikbabu S, Nayak A, Vijayakumar K, Misri Z, Suresh B, Ganesan S, et al. Comparison of physio ball and plinth trunk exercises regimens on trunk control and functional balance in patients with acute stroke: a pilot randomized controlled trial. Clin Rehabil 2011;25(8):709–19.
[39] Chu KS, Eng JJ, Dawson AS, Harris JE, Ozkaplan A, Gylfadóttir S. Water-based exercise for cardiovascular fitness in people with chronic stroke: A randomized controlled trial. Arch Phys Med Rehabil 2004;85:870–3.
[40] Cho KH, Lee WH. Effect of treadmill training based real-world video recording on balance and gait in chronic stroke patients: a randomized controlled trial. Gait Posture 2014;39(1):523–8.
[41] Lee SW, Shin DC, Song CH. The effects of visual feedback training on sitting balance ability and visual perception of patients with chronic stroke. J Phys Ther Sci 2013;25:635–9.
[42] Srivastava A, Taly AB, Gupta A, Kumar S, Murali T. Post-stroke balance training: role of force platform with visual feedback technique. J Neurol Sci 2009;15:89–93.
[43] Lange B, Flynn S, Proffitt R, Chang CY, Rizzo AS. Development of an interactive game-based rehabilitation tool for dynamic balance training. Top Stroke Rehabil 2010;17(5):345–52.
[44] Tsaklis PV, Grooten W, Frazen E. Effects of weight-shift training on balance control and weight distribution in chronic stroke: a pilot study. Top Stroke Rehabil 2012;19(1):23–31.
[45] Morone G, Tramontano M, Iosa M, Shofany J, Iemma A, Musicco M, et al. The efficacy of balance training with video game-based therapy in subacute stroke patients: a randomized controlled trial. Biomed Res Int 2014;1–6.
[46] Cho KH, Lee KJ, Song CH. Virtual-reality balance training with video-game system improves dynamic balance in chronic stroke patients. Tohoku J Exp Med 2012;228(1):69–74.
[47] Llorens R, Gil-Gomez J-A, Alcaniz M, Colomer C, Noe E. Improvement in balance using a virtual reality-based stepping exercise: a randomized controlled trial involving individuals with chronic stroke. Clin Rehabil 2015;29(3):261–8.
[48] Llorens R, Noe E, Colomer C, Alcaniz M. Effectiveness, usability, and cost-benefit of a virtual reality-based telerehabilitation program for balance recovery after stroke: a randomized controlled trial. Arch Phys Med Rehabil 2015;96(3):418–25.
[49] Bauer P, Krewer C, Golaszewski S, Koenig E, Muller F. Functional electrical stimulation-assisted active cycling – therapeutic effects in patients with hemiparesis from 7 days to 6 months after stroke: a randomized controlled pilot study. Arch Phys Med Rehabil 2015;96(2):188–96.
[50] Xiao X, Mao YR, Zhao JL, Li L, Xu GQ, Huang DF. Virtual reality-enhanced body weight-supported treadmill training improved lower limb motor function in patients with cerebral infarction. Chinese J Tissue Eng Res 2014;18(7):1143–8.
[51] YoungJun K, HyunGeun H, Young-Hyeon B, WanHee L. Effect of space balance 3D training using visual feedback on balance and mobility in acute stroke patients. J Phys Ther Sci 2015;27(5):1593–6.
[52] Rensink M, Schuurmans M, Lindeman E, Hafsteinsdóttir T. Task-oriented training in rehabilitation after stroke: systematic review. J Adv Nurs 2008;1–18.
[53] Katz-Leurer M, Sender I, Keren O, Dvir Z. The influence of early cycling training on balance in stroke patients at the subacute stage. Results of a preliminary trial. Clin Rehabil 2006;20:398–405.
[54] Kang HK, Kim Y, Chung Y, Hwang S. Effects of treadmill training with optic flow on balance and gait in individuals following stroke: randomized controlled trials. Clin Rehabil 2011;26(3):245–55.
[55] Yang S, Hwang WH, Tsai YC, Liu FK, Hsieh LF, Chern JS. Improving balance skills in patients who had stroke through virtual reality treadmill training. Am J Phys Med Rehabil 2011;90(12):969–78.
[56] Lau KWK, Mak MKY. Speed-dependent treadmill training is effective to improve gait and balance performance in patient with sub-acute stroke. J Rehabil Med 2011;43:709–13.
[57] Cheng PT, Wang CM, Chung CY, Chen CL. Effects of visual feedback rhythmic weight-shift training on hemiplegic stroke patients. Clin Rehabil 2004;18:747–53.
[58] Tessem S, Hangstrom N, Fallang B. Weight distribution in standing and sitting positions, and weight transfer during reaching tasks, in seated stroke subjects and healthy subjects. Physiother Res Int 2007;12(2):82–94.

[59] Tunf FL, Yang YR, Lee CC, Wang RY. Balance outcomes after additional sit-to-stand training in subjects with stroke: a randomized controlled trial. Clin Rehabil 2010;24:533–42.
[60] Park J, Roh H. Postural balance of stroke survivors in aquatic and land environments. J Phys Ther Sci 2011;23:905–8.
[61] Koog Noh D, Lim JL, Shin HI, Paik NJ. The effect of aquatic therapy on postural balance and muscle strength in stroke survivors – a randomized controlled pilot trial. Clin Rehabil 2008;22:966–76.
[62] Jung JH, Lee JY, Chung EJ, Kim K. The effect of obstacle training in water on static balance of chronic stroke patients. J Phys Ther Sci 2014;26:437–40.
[63] Park J, Lee D, Lee S, Lee Ch, Yoon J, Lee M, et al. Comparison of the effects of exercise by chronic stroke patients in aquatic and land environments. J Phys Ther Sci 2011;23:821–4.