Chapter

Post-Stroke Balance Impairments Assessment: Clinical Scales and Current Technologies

Paulina Ortega-Bastidas, Britam Gómez, Karen Barriga, Francisco Saavedra and Pablo Aqueveque

Abstract

This chapter aims to address the different impairments in the balance after stroke, beginning with an introduction on the main dysfunctions that can be observed, specifically in different transfers as sit-to-stand and gait. Also, a review of the main test and assessment scales most used in the clinical settings in this population. Finally, the application of new technologies and the technological advances used in clinical settings for human analysis focusing on balance are addressed. For example, the types of technologies used, their applications, and the combination with the existing clinical assessment tools. As a closure, we explain the importance of early detection and treatment of balance impairments in the post-stroke population to prevent falls.

Keywords: balance, impairments, stroke, assessment, technology

1. Introduction

All functional activities performed by human beings require adequate postural control to carry them out successfully and efficiently. Postural control is the ability to maintain balance against gravitational forces by maintaining or returning the body mass center on its base support [1, 2]. This emerges from the interaction between subjects, tasks, and environment [2, 3]. Any task requires adequate postural control, but each task also requires an orientation and a stability component [2].

In clinical practices, there is no consensus about only conceptual definitions related to equilibrium, balance, or postural control, and their elements like posture, orientation, and stability. Therefore, it is interesting to at least define basic biomechanical concepts to better understand postural control and further definitions addressed in this chapter.

From a biomechanical point of view, posture refers to the alignment and orientation of the body with respect to its environment [3]. Postural orientation is the ability to maintain an adequate relation between body segments and environment due to performing a task, and postural stability is the ability to control the center of mass within the base support [2, 3].

Nowadays, postural control is no longer considered as only one system or reflex set for upright position and balance, it is considered a complex motor skill due to the interaction of multiple sensorimotor processes [4]. The two main goals of postural control are keeping postural orientation and postural equilibrium [2–4].

The human body in order to achieve stability and orientation requires a complex interaction between musculoskeletal components, neuromuscular synergies, individual sensory systems, sensory strategies, anticipatory and adaptive mechanisms, and internal representations [2]. The central nervous system (CNS) must organize the information coming from the different sensory receptors to determine the position of the body in space [2]. The sensory information coming from the different sensory systems (visual, somatosensory, and vestibular) allows to detect the position of the body and the movement in space in relation to the force of gravity and the environment [2, 3, 5]. Each sense provides specific information about the position and movement of the body, that is, each sense provides different references for postural control [2]. In the higher levels, the CNS sensory information is transformed into significative information, known as perception, and then it is selected the best sensorimotor strategies to achieve the goal of a specific task, to control external perturbance, and to adapt movement to the environmental requirements [2].

Also, postural orientation involves active control of alignment and tone of the body related to gravity, base support, visual information, and internal references [2, 3]. Spatial orientation requires the interpretation and integrated information of the visual, vestibular, and somatosensory systems. On the other hand, postural equilibrium involves the coordination of sensorimotor strategies to control the center of mass during internal and external disturbances [3, 4]. For a better explanation of the different sensory systems and sensory strategies to maintain postural control, see the diagram in **Figure 1**.

There are multiple causes and factors that could lead to dysfunctions in postural control and balance systems. In neurological populations, is commonly observed that

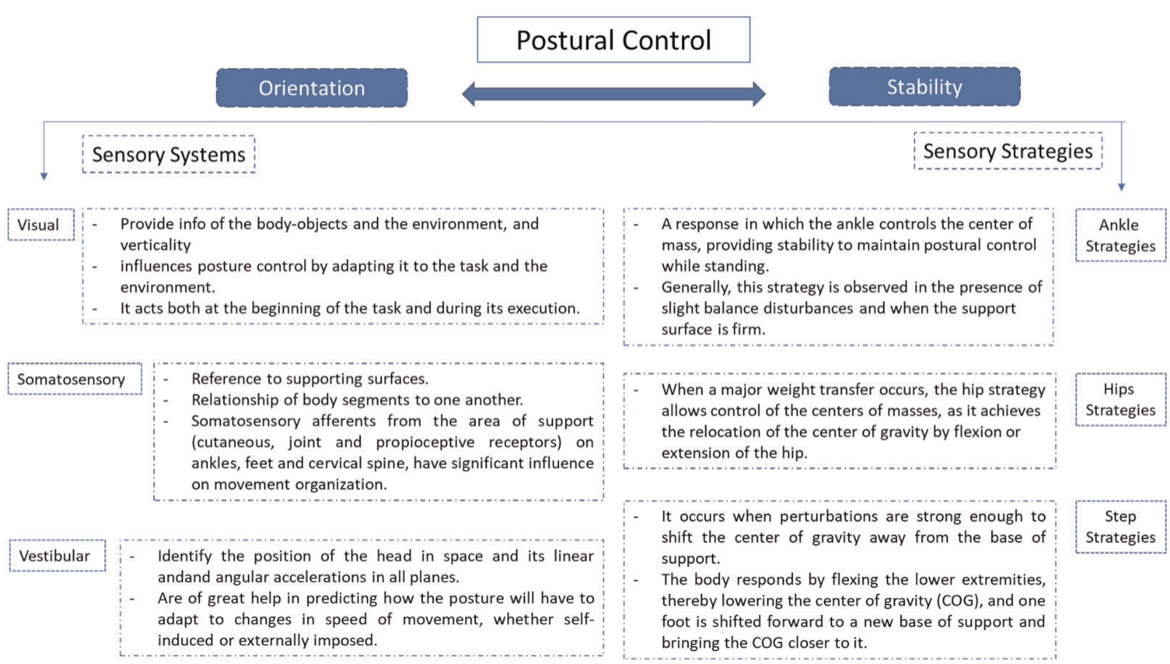

Figure 1.
Postural control by sensory systems and strategies. Summary information collected from Shumway-Cook and Woollacott [2], Cano de La Cuerda [3], Cano de la Cuerda and Callado Vasquez [5].

this deficit affects the ability to stand and walk, increasing the risk of falling and injury [2].

Within neurological populations, we can find stroke patients. Stroke is a common disease [6] that generates great morbidity, mortality, and different degrees of disability, causing a great economic impact on families and society [1].

A stroke can lead to a wide range of impairments that predispose the subjects to falls. One of the principal impairments observed in this population is balance dysfunction [7, 8]. It has been reported that 83% of stroke patients present balance impairments, which lead to gait problems, such as low gait speed and alterations in different gait phases increasing the risk of falling [1]. The incidence of falls in this population within the first six months after a stroke is about 37 and 73%, and the rate of falls in chronic stroke patients is double than healthy subjects [8].

Falls and fear of falling contribute to a sedentary lifestyle with increased limitations in activities of daily living (ADL) and decreased quality of life. In addition, falls increase hospitalization time and generate a large emotional and economic impact for patients, families, and society [1, 9, 10].

The present chapter pretends to expose the principal deficiencies related to balance impairments, observed during the sit-to-stand transfer and gait after a stroke. Also, the main scales and tests for the assessments of balance used in clinical settings, as well as the technologies and new trends that allow for objective analysis of balance dysfunction in this population are reviewed.

2. Principals balance impairments after stroke

As said before, postural control alterations contribute to a loss of stability with a high impact on the quality of life in neurological populations [1, 2]. Balance and postural control impairments cause a series of alterations and dysfunctions during daily life activities, mainly during sit-to-stand transfer and gait [11, 12].

In this section, the main alterations on the sit-to-stand transfer as well as in gait related to balance impairments in post-stroke populations are reviewed.

2.1 Impairments in sit-to-stand transfer after stroke

Sit-to-stand (STS) transfer is considered a fundamental prerequisite to achieve successfully daily life activities [11–13]. Also, it is considered a strong predictor factor of independence and is the main rehabilitation goal because it promotes independent locomotion, as well as upper limb and hand recovery [13]. In post-stroke populations, this transfer is commonly affected, and it is not easy to regain the ability to stand up from a chair safely [11].

The STS transfer has been widely analyzed [11, 14, 15], and has been described as the movement of the body mass center towards the vertical from a sitting position to an upright position without losing balance [11]. This transfer is a transition to the upright position, and it requires a movement of the mass center from a more stable position into a less one with both lower limbs extended [11, 15]. In order to simplify its analysis, the STS transfer has been divided into phases, depending on kinematics variables, ground action forces, and the movement of the mass center [11].

One of these classifications includes four phases for the analysis, considering trunk movement, seat-off, the achievement of an upright position, and the vertical stabilization at the end of the transfer [11]. Another classification considers two principal phases [11, 15], which basically includes three events, onset of STS, seat-off, and end of STS [15].

Associated with this transfer, there have been described different movement determinants in healthy subjects, such as angular displacements of lower limbs and trunk, as well as muscle activation pattern and weight-bearing distribution [16].

Indeed, there are differences in the performance of sit-to-stand transfer between healthy and post-stroke subjects [11, 13–15].

Normally, people with hemiparesis show a loss of coordinated movement between the trunk and knees. Therefore, it can be observed a completed knee extension at the end of the STS despite the hip it is still extending. Also, they show an increased center of pressure and move the trunks in a mediolateral direction towards the non-paretic side, as well as a decreased anterior pelvic tilt [11, 15, 16]. When observed lower limbs, it can be identified less muscle activity in the paretic limb, specifically of tibialis anterior, quadriceps, and soleus, showing problems in the correct activation muscle timing to achieve STS [11, 15].

To avoid the risk of falling, people with stroke adopt compensatory strategies, such as exaggeration of the anterior projection of the center of mass before standing up. This population also shows a decrease in knee moment on the paretic side and an increase in weight distribution asymmetry [11, 15, 16]. It has been suggested a correlation between asymmetry in weight-bearing with functional abilities in stroke. It states that those who carry less weight on their paretic limb obtain poor mobility scores in the functional independence scales. These same results have been demonstrated by Cheng et al. who consider the asymmetric distribution of weight-bearing during STS as a mediator of falls [11, 16].

All of these compensatory strategies are carried out to achieve the sit-to-stand transfer successfully and safely, but this population takes more time in the execution of this task, increasing the risk of falling. Because of the big amount of compensatory strategies used by the stroke population, this transfer is considered an indicator of the risk of falling [11, 16].

2.2 Principal gait impairments after stroke

Similar to STS, independent walking or ambulation is also considered a prerequisite for the performance of activities of daily living [14]. Gait requires an adequate speed to be considered community ambulation, between 1.1 and 1.5 m/s [14]. Also, locomotion is a motor skill, in which control systems in every step must bear weight, give anterior and lateral stability, and keep the center of mass forward, as well as an antigravitatory postural control to provide support and balance to prevent falls [10, 11, 14].

Gait dysfunction represents a major problem in the stroke population and causes difficulties in daily life activities [12, 17]. Approximately 80% of stroke patients experience gait problems in the first 3 months after symptom onset. It has been reported that 18% of subjects are unable to walk, while 11% walk with assistance and the remaining 50% walk independently [12]. It is important to note that only 7% of users who walk independently achieve community walking, which means that they manage to walk 500 meters continuously at an adequate walking speed that allows them to cross the street safely [16].

On the other hand, 70% of stroke patients with community walking suffer falls in the first year, most of these falls are the result of loss in balance. Therefore, there is a high risk of falls in those subjects with stroke who walk independently [12].

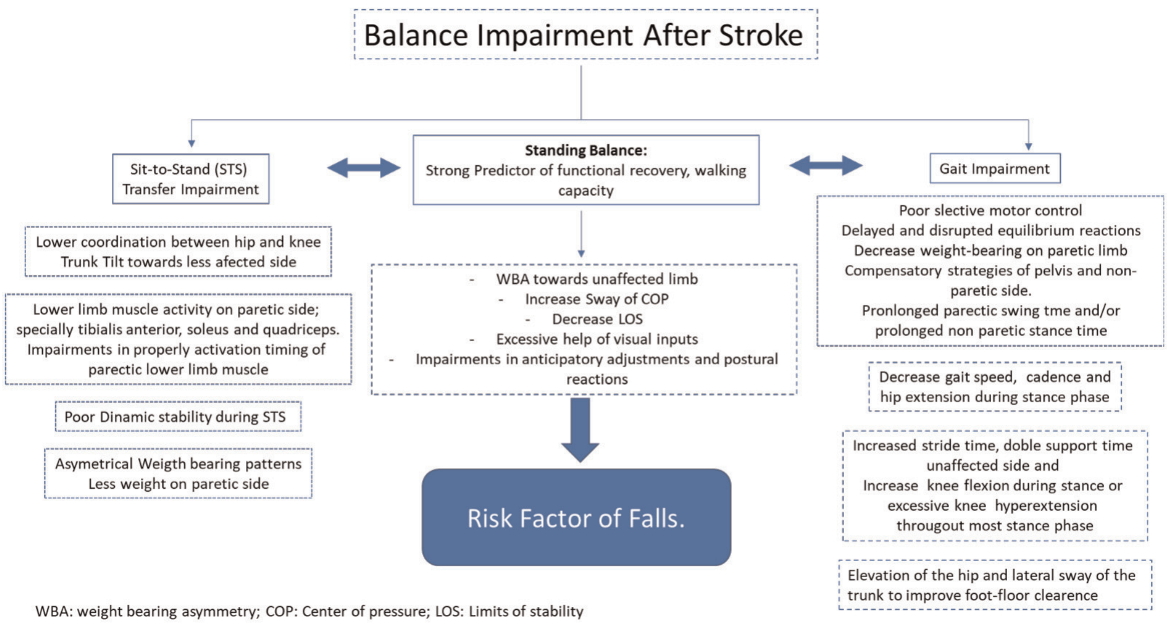

Figure 2.
Balance and gait impairments after stroke. Summary information collected from Boukadida et al. [11], Perry [17], Dickstein [18], Wang et al. [19] Hugues et al. [22], Van Duijnhoven [23], Silva et al. [24], Brière et al. [25], Balandan [26].

Post-stroke gait disturbances and their treatment have been extensively researched [12, 18–20]. Mainly, we could find impairments associated with alterations in spatial-temporal characteristics and biomechanical alterations [12, 19].

Some of the characteristics of hemiparetic gait related to spatiotemporal variables include decreased cadence, prolonged swing duration on the paretic side, prolonged duration on the nonparetic side, and asymmetry in stride length [19]. As well as the increase of the double support phase and the decrease in gait speed [16, 19].

These characteristics contribute to an unsteady gait pattern, leading to restricted walking within the home and an increased risk of falls [21].

In general, due to a stroke, we can observe different impairments that may occur in the paretic lower extremity, such as abnormal recruitment of motor units, muscle weakness, abnormal activation of muscle synergies, spasticity, proprioceptive impairment, restriction in range of motion, which could enhance a poor gait pattern along with balance disturbances and increased risk of falls [13, 18, 22].

Figure 2 shows the main features in balance impairments related to sit-to-stand, standing balance, and gait after stroke. It is important to highlight that there are more features related to each transfer, but we aim to clarify the most common one in this population.

3. Tests and scales for static and dynamic equilibrium assessment

Nowadays, it has become relevant to observe the quality of the movement patterns to discriminate between actual recovery and compensatory movement patterns in stroke rehabilitation [10]. Balance impairments are common in this population and they are determinants factor that influences independence and quality of life; therefore, balance became an important goal to be included in rehabilitation programs [21]. For this purpose, the use of accurate, reliable, and valid assessment tools to measure outcomes in stroke populations related to research and clinical practice is recommended [7].

Normally, rehabilitation professionals perform the evaluation by means of observation and the application of scales and instruments, which provide a certain level of objectivity [27]. Generally, the different methodology used for assessing balance can be divided into observational (e.g., the Romberg test), scales and tests, and testing instrumental equipment (e.g., posturography) [28].

The Berg balance scale (BBS) is a widely used tool in clinical settings and is considered the gold standard for assessing functional balance and fall risk in adults [2, 3, 21, 29]. It has been used extensively to measure outcomes in research involving older adults with a variety of conditions, for example, balance impairments, stroke, Parkinson's disease, vestibular disorders, and in a variety of health care settings [30–32]. It contains 14 items related to the static and dynamic tasks of daily living [3]. The tasks on this scale progress in difficulty from sitting to bipedal, to bipedal with a narrow support base, to tandem gait and one leg support. The score is calculated on a 5-point ordinal scale for each item, where 0 refers to the inability to complete the test and 4 refers to being able to complete the test independently [3, 29]. The maximum score is 56 points that indicates adequate postural balance and no risk of falls, and a score equal to or less than 45 points indicates a risk of falls [3]. Specifically, values between 56 and 41 points indicate a low risk of falling, between 40 and 21 points a medium risk of falling, and between 20 and 0 points a high risk of falling. Its application lasts between 10 and 20 minutes [29–32]. Another widely used test is the Timed up and Go (TU & Go) test, which measures dynamic balance and functional mobility in adults, as well as in the neurological population [33–35]. The TU & Go is a simple test that can be applied anywhere and consists of the subject standing up from a chair, walking three meters, turning around, walking back to the chair, and sitting down on the chair again. The controlled variable is the total time in seconds the subject takes to perform the test, which is then correlated with the risk of falling [34–36]. Score assumed to be normal if the time is ≤10 seconds, mild risk of falling between 11 and 20 seconds, and high risk >20 seconds [37]. This test has demonstrated excellent inter- and intra-rater reliability with values greater than 0.95, with adequate predictive value for falls in older adults and stroke patients [38, 39]. Some advantages of the TU & Go test are its simplicity and short duration of application. Additionally, it requires little equipment and allows subjects with functional impairment to perform the test [3]. However, one limitation is that although it provides information on the risk of falls, it is not able to determine the risk objectively in subjects with greater difficulties. Barry et al. mention that a limitation in the predictive value of the test could be explained by the fact that it is a single test that evaluates balance and equilibrium in a general way. Therefore, it could be improved by being combined with technological tools for motion analysis [40].

Commonly, in clinical practice, this test is combined with the application of other clinical tests such as the 10-meter walk test, and its results are compared with those obtained in the Berg balance scale [30]. These tests as a whole make it possible to assess the risk of falls, walking speed, and balance of the different patients, making it possible to objectively assess their functional level and to determine the relevant intervention strategies.

Gait speed has been shown to be a predictor for different clinical outcomes, such as response to rehabilitation, level of dependency, frailty, disability, falls, institutionalization, cognitive loss, hospitalization, cardiovascular events, and mortality. Its decrease has been associated with a lower quality of life, social participation, and the presence of depressive symptoms [41]. Middleton et al. define it as the sixth vital sign due to its broad predictive capacity. The 10-meter walk test has proven to be a robust, validated, reliable, and sensitive tool that can be applied in both clinical and research contexts, and in a wide range of pathologies, such as the elderly, chronic stroke, incomplete spinal cord injury, multiple sclerosis, Parkinson's disease, among others [18, 38, 41, 42].

This test measures walking speed in meters per second (m/s) when walking a short distance of 10 meters. Then, the value obtained will be categorized into the four categories proposed by Perry et. Al, which are intra-domicile gait with speeds between 0 to 0.4 ms; dependent community gait with speeds from 0.4 to 0.8 m/s; community gait 0.8 to 1.2 m/s; and safe gait for crossing the street greater than 1.2 m/s [43].

On the other hand, there is the Functional Reach Scale. This scale was developed to assess the maximum limits of standing stability. Subjects are held in a standing position with feet shoulder-width apart and with one arm (hand grasped) elevated to 90 degrees of flexion. Without moving the feet, the patient is asked to reach as far as possible without losing balance. The distance reached is measured and compared with standardized references by age group as defined by Duncan et al. The functional reach test has satisfactory inter-rater reliability and has been reported as a predictor of falls in older adults [2, 3].

Table 1 summarizes some specific characteristics of the tests and scales listed before.

Test/scale	Aim	Area	Assessment	Description	Cost	Duration
Berg balance scale [3, 44]	Static balance and risk of falling.	Balance, functional mobility.	Performance measurement (score).	Scale that considers 14 items that include static and dynamic activities of varying difficulty. Each activity is evaluated from 0 to 4 points, determined by the patient's ability to perform the activity in question. Maximum score 56.	Free (Paper and pencil)	10 to 20 min.
Timed up and go [37, 44]	Risk of falling.	Balance, functional mobility, vestibular assessment.	Observer.	Subject begins seated with his back against the back of a chair. At the beginning of the test, the patient gets up from the chair and walks 3 meters, and then turns and returns to the starting point and sits down. The time taken to complete the circuit is recorded.	Free (paper and pencil)	≤3 min.
10-M walk test [43, 44]	Independence level.	Mobility, gait, vestibular assessment.	Performance measurement (gait speed).	Subject walks a predetermined distance (depending on the variation applied), in which time is measured. The distance walked in meters is divided by the measured time.	Free (paper and pencil)	≤ 5 min.

Test/scale	Aim	Area	Assessment	Description	Cost	Duration
Tinetti [44]	Balance perception and stability during daily life activities.	Daily life activities, Balance, Functional Mobility, Gait, and Vestibular Assessment.	Patients perception.	10-item questionnaire designed to assess patient confidence in performing 10 activities of daily living without risk of falling as an indicator of how fear of falling impacts physical performance. The higher the score (100 max) the lower the patient's confidence.	Free (paper and pencil)	10 to 15 min.
BESTest [44–46]	Postural stability and balance.	Balance, functional mobility, vestibular assessment.	Performance measurement (score).	Orients and identifies the six balance control systems in order to design better approaches to balance rehabilitation from 35 items in six sections, evaluated from 0 to 108 points.	Free (paper and pencil)	10 to 20 min.
Activities of Balance confidence (ABC) scale [44]	Self-reporting of the balance confidence measure.	Balance, functional mobility.	Patients perception.	Subjective measure of confidence to perform various ambulatory activities without falling or experiencing feelings of instability out of 16 activities scored from 0 (no confidence) to 100 (confidence).	Free (paper and pencil)	5 to 10 min.

Table 1.
Test and scale for the assessment of balance in stroke populations.

One of the most recent scales to measure balance is the Balance Evaluation Systems Test (BESTest), which is a balance assessment scale that allows identifying specific problems in postural control, such as biomechanical alterations, stability limits, postural response, anticipatory postural adjustments, sensory orientation, dynamic balance during gait, and cognitive effects. Although it is a new multitask scale, it includes 36 items to be evaluated with an estimated application time of 30 to 35 minutes [2, 3, 45, 46]. Its short version, the Mini-Balance Evaluation Systems Test (Mini-BESTest), was created in 2010, which contemplates 14 items and takes a total of 10 minutes to complete the assessment, with good inter- and intra-rater reliability in a sample of people with mixed conditions. The mini-BESTest has been shown to be a reliable and validated tool for assessing balance in chronic stroke patients [47].

As can be seen in this section, there is a wide range of scales and clinical tests that allow not only to assess balance but also to observe how the different components behave during the performance of different tasks. Some of them are not only validated in populations with stroke. Therefore, the reader is suggested to review the specific psychometric properties of each of them and their validation in other neurological populations before using it.

4. Balance impairment treatments after stroke

There are different therapeutic interventions to improve balance after stroke. According to Stein et al. [21] these interventions could be categorized into five main areas, exercise programs, biofeedback training, sensory training, cognitive training, and external devices.

Each of these areas will address different aspects of the multiple problems that can be found associated with balance impairments [21, 22]. Exercise programs are varied in form, maybe individual or group-based, and include a variety of impairment-oriented elements. Some may include functional activities such as sit-to-stand and balance tasks due to daily life activities, for example, reaching and standing on unstable surfaces [21].

Also, there are different intervention models such as constraint-induced therapy, task-oriented approach, as well as neurophysiological intervention approach such as the Bobath concept, proprioceptive neuromuscular facilitation, and other neurodevelopment models, which have been traditionally used in the treatment of post-stroke patients [5].

The incorporation of visual and sensory training has been shown to be effective in the treatment of balance, as well as the promotion of weight-bearing in seated and upright positions [21–23, 48]. On the other hand, the incorporation of therapeutic strategies that involve trunk work in the recovery of dynamic balance during sitting, sit-to-stand, and gait is relevant [49].

Since, trunk function has been associated with gait and balance ability in stroke patients and has been shown to be a useful predictor of recovery of gait, balance, and activities of daily living [49].

Recently, a meta-analysis by Hugues et al. concluded that physical therapy has various benefits on postural balance and stability after stroke. It suggests that functional task training, associated with musculoskeletal and/or cardiopulmonary interventions, as well as sensory interventions, appear to be effective in improving balance and postural stability. However, the authors ask for caution with this result, due to “the weak methodological quality of studies,” among other methodological elements [21, 42].

Even though there are several therapeutic approaches and categories of physical therapy, we believe it is important to highlight that each exercise program should be individualized according to the individual’s own capabilities and should be supervised by a therapist.

5. Technological tools and systems for the evaluation and treatment in post-stroke patients

5.1 Technological tools for monitoring and for the diagnostic support of post-stroke patients

At a commercial level, a large number of technological systems allow to evaluate different aspects of gait, balance, and strength beyond the typical clinical methodologies, as seen in the previous section.

From the perspective of systems that are capable of evaluating movement and even mobility variables for clinical use, there are camera-based motion analysis laboratories whose measurement is carried out using software for motion analysis (**Figure 3**).

On the other hand, in the last 30 years, there has been an increase in the use of inertial sensors for motion analysis, whose reduction in size and consumption, in addition to the improvement in algorithms for motion tracking, have allowed them to be positioned as an attractive alternative for the study of movement objectively and quantitatively (**Figure 4**).

Some other commercial alternatives are illustrated in **Table 2**.

Another type of element is highly used in the clinical field for the evaluation of gait and static and dynamic balance correspond to systems that measure plantar pressures for the estimation of mobility variables. Technological alternatives range from highly accurate mats for gait and balance evaluation, to systems that embed pressure sensors within insoles to evaluate uncontrolled environments (**Figure 5**).

Some other examples are illustrated in **Table 3**.

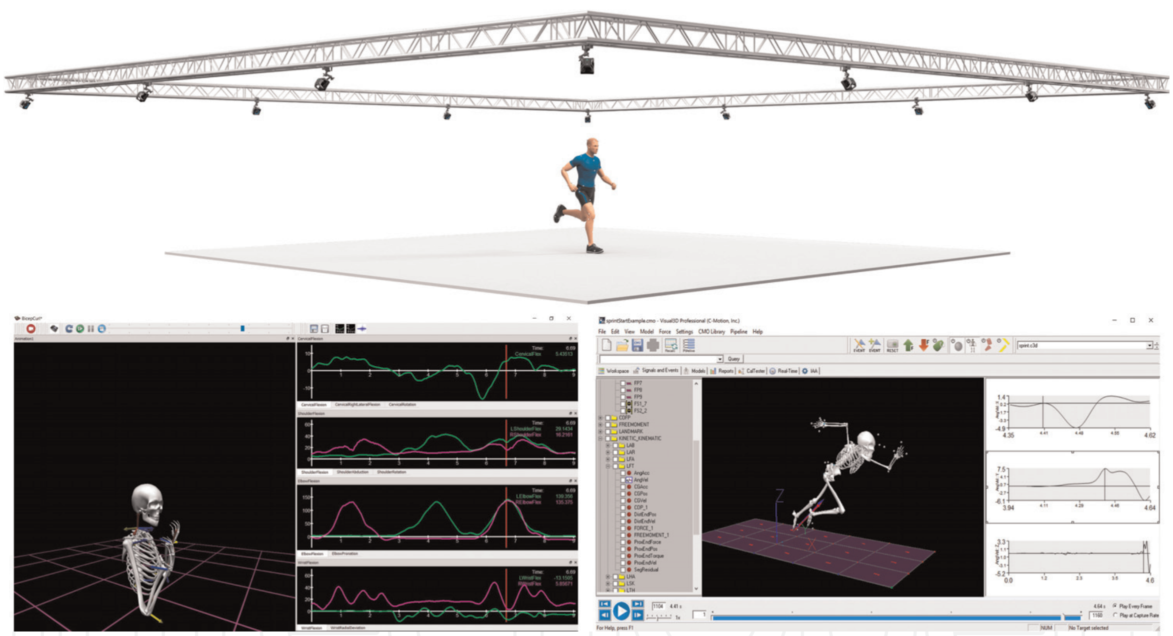

Figure 3.
Optitrack system for human motion analysis using a camera-based system. Image obtained from Optitrack official website [50].

Figure 4.
Inertial-based systems for a clinical movement analysis perspective. From left to right: APDM mobility lab, G-walk, and QMUV. Images obtained from the official website of G-walk [51], APDM [52], and QMUV [63].

System	Technology	Description	Area
Vicon [54]	Optic	Leading optical system in motion analysis used in both clinical and entertainment applications. It incorporates the ability to track reflective passive markers and, together with its tracking platform, it is possible to capture the movement made by people. Using its proprietary software, such as NEXUS, clinical biomechanical and sports motion analysis can be performed. It also offers the possibility of performing biomechanical analysis by incorporating other analysis software, such as Biomechanics of Bodies.	Clinical, sports, entertainment, academic
Optitrack [50]	Optic	Optical system that incorporates a flexible system to perform biomechanical motion analysis, providing the possibility of natively incorporating other commonly used tools for motion analysis such as electromyography modules, force platforms, and analog sensors. Incorporates the ability to track passive reflective and active markers. It allows the use of other analysis software commonly used in the academic research area such as in Visual3D, The MotionMonitor, MATLAB, and Biomechanics of Bodies.	Clinical, sports, entertainment, academic
MTw Awinda – X-SENS [55]	Inertial	System with inertial technology that incorporates the possibility of evaluating variables of acceleration, speed, and ranges of movement of some segments or the whole body including hands and phalanges. It offers the possibility of performing biomechanical analysis by incorporating other analysis software such as Biomechanics of Bodies.	Clinical, sports, entertainment, academic
Perception Neuron – NOITOM [56]	Inertial	System with inertial technology that incorporates the possibility of evaluating variables of acceleration, speed, and ranges of movement of some segments or the whole body including hands and phalanges. It offers the possibility of performing biomechanical analysis by incorporating other analysis software such as Biomechanics of Bodies.	Entertainment, academic
Ultium Motion – Noraxon [57]	Inertial	System with inertial technology that incorporates the possibility of evaluating variables of acceleration, speed, and ranges of movement of some segments or the whole body with a maximum of 16 sensors.	Clinical, sports, entertainment
G-WALK [51]	Inertial	Sensorization of several clinical tests with a single inertial sensor to assess gait, balance, ranges of motion, and risk of falls. In addition to the incorporation of evaluation of aspects of sports performance such as jumping power and aerobic resistance.	Clinical, sports, academic
MobilityLab – APDM [52]	Inertial	Matrix of six inertial sensors that measure different aspects of gait and risk of falls.	Clinical, academic
QMUV [53]	Inertial	Sensorization of several clinical tests with a single inertial sensor to assess gait, balance, ranges of motion, and risk of falls.	Clinical, academic

Table 2.
Commercial technological alternatives used to evaluate motor impairment conditions in post-stroke patients.

System	Description	Area
Xsensor [58]	Insoles with plantar pressure points to measure gait variables in sports and clinical applications.	Clinical, sports
Moticon [60]	Insole for gait analysis in rehabilitation and sports training.	Clinical, sports
Feetme–Health [61]	Insole with inertial sensor analysis and plantar pressure point for clinical-grade measurement of spatiotemporal variables of gait.	Clinical
GAITRite [59]	Gait analysis mat, leader in analysis for spatiotemporal variables of the gait cycle.	Clinical, academic
P-Walk [62]	Mat that measures static balance variables through the acquisition of postures and control of the center of mass and spatiotemporal variables of the gait cycle.	Clinical, academic

Table 3.
Technological systems to assess motor impairments using plantar pressures in post-stroke patients.

Figure 5.
Pressure-based systems to analyze gait and posture. From left to right: GAITRite and Xsensor. Images obtained from the official website of Xsensor [58] and GAITRite [59].

5.2 Technological systems for post-stroke patients rehabilitation

As mentioned at the beginning of this section, the technological tools for the treatment of post-stroke subjects seek to reduce the impact of the disabling condition to improve the quality of life of the patient through rehabilitation therapies to train or adapt the lost function.

From this perspective, the development of serious games for rehabilitation has taken on great importance in the treatment since, they make patients hooked on their treatment, avoiding problems associated with early abandonment from their therapies. Systems that use interactive platforms such as the famous Kinect (camera system) [63] and Nintendo Wii (multisensory system with inertial control and pressure platform) [64] started a massive adoption in the field of game development to support the rehabilitation. However, although they continue to be used in clinical settings for interactive treatment, these technologies are no longer commercially available and are obsolete.

Because of the great technological advance in animation and graphic processing systems, serious games for immersive or semi-immersive rehabilitation using virtual reality helmets (HTC-vive, Oculus, among others) have allowed to establish an environment that mimics in controlled conditions in the daily life of people in order to train typical activities such as brushing teeth, cooking and eating in a safe environment [65]. Also, semi-immersive elements have made it possible to instrumentalize the highly used mirror movement test to increase patients' perception of movement. All these systems that support the mobility of the upper and lower extremities allow the development of augmented reality environments or interactive systems that enrich the experience of the patient and provide more information about the patient's condition [66]. Some commercial rehabilitation options include Tyromotion's PABLO (interactive upper extremity therapy), TYMO (interactive system for balance and coordination training), and DIEGO (interactive arm and shoulder rehabilitation) systems (**Figure 6**) [67].

Leaving aside the treatment systems and focusing on systems that have the potential to be used in everyday life, functional electrical stimulation tools (FES) appear, which correspond to systems that, through the injection of controlled electrical pulses, allow to recover the mobility of limbs, improving grip in upper limb cases and improving gait in case of foot drop stimulators. Although upper limb stimulators have not yet become widespread, in the literature, there is great evidence of efforts by researchers to generate alternatives to train or regain mobility of the arms and hands. Alternatively, and more commonly, there are electronic orthoses for droop foot, where by means of a system that allows the generation of controlled pulses from the detection of gait cycle events, the control of dorsiflexion can be recovered in post-stroke patients [68]. Commercial examples are SmartFES, XFT-2001, ODFS Pace, among others (**Figure 7**) [68–70].

On the other hand, health professionals and the scientific community have developed alternatives to treat post-stroke who, due to different factors such as economical, geographical, physical, and/or environmental, are unable to attend rehabilitation centers. The need for the above has increased as a result of the recent COVID-19

Figure 6.
Interactive rehabilitation systems developed from Tyromotion. From left to right: PABLO, TYMO, and DIEGO. Images obtained from the official website of Tyromotion [67].

Figure 7.
Functional electrical stimulation systems commercially available. From left to right: ODFS pace, SmartFES, and XFT-2001. Images obtained from the official website of SmartFES [68], XFT-2001 [69], and Odstock [70].

pandemic that incorporates post-stroke people as a population at risk [71]. Regarding this, different types of treatment that use technology to rehabilitate communication skills [72], upper limb rehabilitation, and/or remote activities of daily living have been evaluated, proving to be almost as effective as face-to-face treatments. Although there is a lack of information on the cost-effectiveness relationship with respect to traditional treatments, it is evident that the role of telerehabilitation is of vital importance in rural areas or in health emergencies where patients do not have access to opportune care or monitoring of their condition [73, 74].

In this section, some tools typically used for the evaluation and treatment of post-stroke patients are mentioned. However, the intention is to provide a general overview of the systems most used internationally, existing alternatives that improve their proposal in terms of accessibility and costs.

6. Conclusion

Stroke generates primary and secondary impairments that reduce the functional capacity of these patients, leading to less functional independence and quality of life. One of the main impairments associated with this population is impaired balance, both static and dynamic. This impairment in particular generates a great impact on the dysfunction of activities of daily living and main transfers such as bipedal sedentary transfer and gait. Moreover, in this pathology, 14–65% of individuals fall at least once in the hospital, and between 37 and 73% suffer falls in the next 6 months after discharge [75].

Specifically, people with stroke are at increased risk of fall-related fractures. Other adverse consequences may include fear of falling with subsequent reduction in activity, de-conditioning, and increased risk of falls. Bower et al. state that it has recently been shown that the identification of movement and balance variables, for example by measuring walking speed, application of the timed up and go test, and the Berg Balance Scale, have been shown to be strong predictors of fall risk following stroke [8].

However, as mentioned above, there are some deficiencies in the clinical tests and scales, since they fail to fully determine the variables and problems associated with balance impairment. The use of clinical scales and tests, associated with the use of technologies, could allow the adequate assessment of each of the limitations in static and dynamic balance during the different transfers performed by people with sequelae of stroke.

In this chapter, we have presented a list of alternatives to treat and evaluate the stroke patient in all phases of treatment, providing plenty of evidence of systems for movement analysis and treatment, especially useful for the treating professional, and of highly technological elements to improve adherence to rehabilitation therapies.

Finally, it is important to highlight that a specific assessment of the impairments that contribute to an unfavorable balance in subjects with stroke is necessary for each rehabilitation process, as well as the early incorporation of functional therapeutic activities aimed at their recovery and the prevention of the risk of falls.

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Conflict of interest

Pablo Aqueveque, Britam Gómez and Francisco Saavedra were developers of SmartFES and QMUV devices. The remaining authors have no conflicts of interest to declare.

Author details

Paulina Ortega-Bastidas[1,2*], Britam Gómez[3], Karen Barriga[1], Francisco Saavedra[3] and Pablo Aqueveque[3]

1 Faculty of Medicine, Kinesiology Department, Universidad de Concepción, Concepción, Chile

2 Health Sciences PhD Programme, Universidad Rey Juan Carlos, Madrid, Spain

3 Faculty of Engineering, Electrical Engineering Department, Universidad de Concepción, Concepción, Chile

*Address all correspondence to: portegab@udec.cl

References

[1] Li J, Zhong D, Ye J, et al. Rehabilitation for balance impairment in patients after stroke: A protocol of a systematic review and network meta-analysis. BMJ Open. 2019;**9**:e026844. DOI: 10.1136/bmjopen-2018-026844

[2] Shumway-Cook A, Woollacott M. Control Motor de la Investigación a la práctica Clínica. 5th ed. Alphen aan den Rijn, Netherlands: Wolter Kluwer; 2017. pp. 228-229

[3] Cano de La Cuerda R, Piédrola M, Miangolarra P. Control y Aprendizaje Motor. Fundamentos, desarrollo y reeducación del movimiento humano. Panamericana. 2017

[4] Horak FB. Postural Orientation and equilibruim: What do we need to know about neural control of balance to prevent falls? Age and Ageing. 2006;**35–S2**:ii7-ii11. DOI: 10.1093/ageing/afl077

[5] Cano de la Cuerda R, Callado Vasquez S. Neurorrehabilitación, Métodos específicos de valoración y tratamiento. Panamericana. 2012

[6] Winstein CJ et al. Guidelines for adult stroke rehabilitation and recovery. Stroke. 2016;**47**:e98-e169. DOI: 10.1161/STR.0000000000000098

[7] Bower KJ, McGinley JL, Miller KJ, Clark RA. Instrumented static and dynamic balance assessment after stroke using Wii Balance Boards: reliability and association with clinical tests. PloS One. 2014;**9**(12):e115282. DOI: 10.1371/journal.pone.0115282

[8] Bower K et al. Dynamic balance and instrumented gait variables are independent predictor of falls following stroke. Journal of NeuroEngineering and Rehabilitation. 2019;**16**:3. DOI: 10.1186/s12984-018-0478-4

[9] Goh H-T et al. Falls and Fear of Falling after Stroke: A case-control study. PM & R : The Journal of Injury, Function, and Rehabilitation. 2016;**8**:1173-1180

[10] Merchant RA et al. Relationship between fear of falling, fear related activity, restriction, frailty and sarcopenia. Journal of the American Geriatrics Society. 2020;**68**:2602-2608. DOI: 10.1111/jgs.16719

[11] Boukadida A, Piotte F, Dehail P, Nadeau S. Determinant of sit-to-stand tasks in individual with hemiparesis post stroke: A review. Annals of Physical and Rehabilitation Medicine. 2015;**58**:167-172. DOI: 10.1016/j.rehab.2015.04.007

[12] Beyaert C, Vasa R, Frykberg GE. Gait post-stroke: Pathophysiology and rehabilitation strategies. Clinical Neurophysiology. 2015;**45**:335-355

[13] Raine S, Meadows L, Lynch-Ellerington M. Bobath Concept. Theory and Clinical Practice in Neurological Rehabilitation. New York: Wiley-Blackwell; 2009. p. 83, 84, 117

[14] Chen HB, Wei TS, Chang LW. Postural Influence strategies and sitting impact forces in stroke patients. Gait and Posture. 2010;**32**:576-580. DOI: 10.1016/j.gaitpost.2010.08.005

[15] Van Bladel A, Kilinc O, De Ridder R, Kılınc M. Trunk and lower extremity biomechanics during sit-to-stand activity after stroke. Gait and Posture. 2021;**90**:280. DOI: 10.1016/j.gaitpost.2021.09.145

[16] Carr J, Seperd R. Rehabilitación en el paciente con Ictus, recomendaciones para optimizar las habilidades motoras. Amsterdam, Netherlands: Elsevier España; 2004

[17] Perry J. Gait Analysis, Normal and Pathological Function. West Deptford, NJ: Slack Incorporated; 1992

[18] Dickstein R. Rehabilitation of Gait Speed After Stroke: A critical review of intervention approaches. Neurorehabilitation and Neural Repair. 2008;**22**(6). DOI: 10.1177/1545968308315997

[19] Wang Y, Mukaino M, Otsuka K, Otaka H, et al. Gait characteristics of post-stroke hemiparetic patients with different walking speeds. International Journal of Rehabilitation Research. 2020;**43**:69-75. DOI: 10.1097/MRR.0000000000000391

[20] Wonsetler E, Bowden M. A systematic review of mechanisms of gait speed post stroke. Part 1: Spatiotemporal parameter and asymmetry ratios. Topics in Stroke Rehabilitation. 2017;**24**(6):435-446. DOI: 10.1080/10749357.2017.1285746

[21] Stein J, Harvey R, Macko R, Winstein C, Zorowitz R. Stroke Recovery and Rehabilitation. New York: Demos Medical Publishing; 2009

[22] Hugues A, Di Marco J, Ribault S, Ardaillon H, Janiaud P, Xue Y, et al. Limited evidence of physical therapy on balance after stroke: A systematic review and meta-analysis. PLoS One. 2019;**14**(8):e0221700. DOI: 10.1371/journal.pone.0221700

[23] Van Duijnhoven H, Heeren A, Peters M, Veerbeck J, Kwakkel G, et al. Effects of exercise therapy on balance capacity on chronic stroke. Stroke. 2016;**47**:2603-2610. DOI: 10.1161/STROKEAHA.116.013839

[24] Silva A, Sousa AS, Pinheiro R, Ferraz J, Tavares JM, Santos R, et al. Activation timing of soleus and tibialis anterior muscles during sit-to-stand and stand-to-sit in post-stroke vs. healthy subjects. Somatosensory & Motor Research. 2013;**30**(1):48-55. DOI: 10.3109/08990220.2012.754755

[25] Brière A, Nadeau S, Lauziére S, Gravel D. Perception of weight—Bearing and Effort distribution during sit-to-stand in individuals post-stroke. Perceptual & Motor Skills: Motor Skills & Ergonomic. 2013;**117**(1):166-181

[26] Balandan B. Gait Disturbance in Patients with Stroke. PM & R. 2014;**6**:635-642. DOI: 10.1016/j.pmrj.2013.12.017

[27] Park SH. Tools for assessing fall risk in the elderly: A systematic review and meta-analysis. Aging Clinical and Experimental Research. 2018;**30**:1-16

[28] Lin Q, Zheng Y, Lian P, Guo Y, Huang H, Luo Z, et al. Quantitative static and dynamic assessment of balance control in stroke patients. Journal of Visualized Experiments. 2020;**159**:e60884. DOI: 10.3791/60884

[29] Pickenbrock H, Diel A, Zpaf A. A comparison between the static balance test and the Berg Balance Scale: Validity, reliability, and comparative resource use. Clinical Rehabilitation. 2016;**30**(3):288-293. DOI: 10.1177/0269215515578297

[30] Neuls PD, Clark TL, Van Heuklon NC, Proctor JE, Kilker BJ, et al. Usefulness of the berg balance scale to predict falls in the elderly. Journal of Geriatric Physical Therapy. 2011;**34**:3-10

[31] Donoghue D, Stokes E. How much change is true change. The minimum detectable change of the berg balance scale in elderly people. Journal of Rehabilitation Medicine. 2009;**41**:343-346

[32] Lusardi MM. Functional performance in community living older adults. Journal of Geriatric Physical Therapy. 2004;**26**(3):14-22

[33] Zasadzka E, Borowicz AM, Roszak M, Pawlaczyk M. Assessment of the risk of falling with the use of timed up and go test in the elderly with lower extremity osteoarthritis. Clinical Interventions in Aging. 2015;**10**:1289

[34] Persson CU, Danielsson A, Sunnerhagen KS, Grimby-Ekman A, Hansson PO. Timed Up and Go as a measure for longitudinal change in mobility after stroke–Postural Stroke Study in Gothenburg (POSTGOT). Journal of Neuroengineering and Rehabilitation. 2014;**11**:83

[35] Nguyen H, Lebel K, Boissy P, Bogard S, Goubault E, Duval C. Auto detection and segmentation of daily living activities during a timed up and go task in people with Parkinson's disease using multiple inertial sensors. Journal of Neuroengineering and Rehabilitation. 2017;**14**:26

[36] Podsiadlo D, Richardson S. The timed Up and Go: A test of basic functional mobility for frail elderly persons. Journal of the American Geriatrics Society. 1991;**39**:142-148

[37] Mancilla E. Rendimiento en las pruebas Timed up and Go y Estación Unipodal en AM chileno entre 60 y 89 años. Revista medica de Chile. 2015;**143**: 39-46

[38] Flansbjer U. Realiability of gait performance tests in men and women with hemiparesis after stroke. Journal of Rehabilitation Medicine. 2005;**37**:75-82

[39] Hafsteinsdóttir T. Clinimetric properties of the timed up and go test for patients with stroke: A systematic review. Topics in Stroke Rehabilitation. 2014;**21**(3):197-210

[40] Barry E, Galvin R, Keogh C, Horgan F, Fahey T. Is the timed up and go test a useful predictor of risk of falls in community dwelling older adults: A systematic review and meta-analysis. BMC Geriatrics. 2014;**14**:14

[41] Middleton A, Lusardi M. Walking sped: The functional vital sign. Journal of Aging and Physical Activity. 2015;**23**(2): 314-322

[42] Tysson S, Connel L. The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions. A systematic review. Clinical Rehabilitation. 2009;**23**:1018-1033

[43] Perry J, Garret M, Gronley JK, Mulroy SJ. Classification of waling handicap in the stroke population. Stroke. 1995;**26**(6):982-989

[44] Shirley Ryan—Abilitylab. Available from: https://www.sralab.org/ [Accessed: July 19, 2021]

[45] Tsang C et al. Psychometric properties of the mini-balance evaluation systems test (Mini-BESTest) in community-dwelling individuals whit chronic stroke. Physical Therapy. 2013; **93**:1102-1115

[46] Horak F, Wrisley D, Frank J. The balance evaluation systems test (BESTest) to differentiate balances defitics. Physical Therapy. 2009;**89**(5): 484-498. DOI: 10.2522/ptj.20080071

[47] Di Carlo S et al. The mini-BESTest: A review of psychometric properties. International Journal of Rehabilitation Research. 2016;**39**:97-105

[48] Hawyama K, Kawakami M, Otsuka T. Effect of core stability training on trunk function, standing balance, and mobility in Stroke patients: A randomized controlled trial. Neurorehabilitation and Neural Repair. 2017;**31**(3):240-249. DOI: 10.1177/1545968316675431

[49] Timmermans AA, Seelen HA, Willmann RD, Kingma H. Technology-assisted training of arm-hand skills in stroke: Concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design. Journal of Neuroengineering and Rehabilitation. 2009;**6**(1): 1-18

[50] Optitrack System. Available from: https://optitrack.com/ [Accessed: November 5, 2021]

[51] G-Walk System. Available from: https://www.btsbioengineering.com/es/products/g-walk/ [Accessed: November 10, 2021]

[52] Mobility Lab System. Available from: https://apdm.com/mobility/ [Accessed: November 15, 2021]

[53] QMUV Inertial System. Available from: https://qmuv.cl/ [Accessed: November 1, 2021]

[54] Vicon System. Available from: https://www.vicon.com/ [Accessed: November 3, 2021]

[55] MTw Axinda System. Available from: https://www.xsens.com/products/mtw-awinda [Accessed: November 2, 2021]

[56] Perception Neuron Pro System. Available from: https://neuronmocap.com/ [Accessed: October 28, 2021]

[57] Ultium Motion System. Available from: https://www.noraxon.com/our-products/ultium-motion/ [Accessed: November 7, 2021]

[58] Xsensor Insole System. Available from: https://es.xsensor.com/ [Accessed: November 5, 2021]

[59] GAITRite Mat System. Available from: https://www.gaitrite.com/ [Accessed: November 7, 2021]

[60] Moticon Insole System. Available from: https://moticon.com/ [Accessed: November 6, 2021]

[61] Feetme–Health Insole System. Available from: https://feetmehealth.com/insoles/ [Accessed: November 6, 2021]

[62] P-Walk Mat System. Available from: https://www.btsbioengineering.com/products/p-walk/ [Accessed: November 7, 2021]

[63] Ferreira D, Oliveira R, Postolache O. Physical rehabilitation based on kinect serious games. In: Eleventh International Conference on Sensing Technology (ICST). New York: IEEE; 2017. pp. 1-6

[64] Dos Santos LRA, Carregosa AA, Masruha MR, Dos Santos PA, Coêlho MLDS, Ferraz DD, et al. The use of nintendo wii in the rehabilitation of poststroke patients: A systematic review. Journal of Stroke and Cerebrovascular Diseases. 2015;**24**(10):2298-2305

[65] Wade E, Winstein CJ. Virtual reality and robotics for stroke rehabilitation: Where do we go from here? Topics in Stroke Rehabilitation. 2011;**18**(6): 685-700

[66] Loureiro RC, Harwin WS, Nagai K, Johnson M. Advances in upper limb stroke rehabilitation: A technology push. Medical and Biological Engineering and Computing. 2011;**49**(10):1103-1118

[67] Tyromotion Products. Available from: https://tyromotion.com/en/product-overview/ [Accessed: November 20, 2021]

[68] Aqueveque P, Ortega P, Pino E, Saavedra F, Germany E, Gómez B. After stroke movement impairments: A review of current technologies for rehabilitation. Physical Disabilities-Therapeutic Implications. 2017;**10**:95-116

[69] SmartFES System. Available from: http://smartfes.cl/ [Accessed: November 12, 2021]

[70] Odstock System. Available from: https://odstockmedical.com/prod-category/stimulators/ [Accessed: November 12, 2021]

[71] Chang, M. C., and Boudier-Revéret, M. (2020). Usefulness of Telerehabilitation for Stroke Patients during the COVID-19 Pandemic. American Journal of Physical Medicine and Rehabilitation 997 p 582 doi: 10.1097/PHM.0000000000001468

[72] Agostini M, Garzon M, Benavides-Varela S, De Pellegrin S, Bencini G, Rossi G, et al. Telerehabilitation in poststroke anomia. BioMed Research International. 2014;**2014**:1-6. DOI: 10.1155/2014/706909

[73] Johansson T, Wild C. Telerehabilitation in stroke care—A systematic review. Journal of Telemedicine and Telecare. 2011;**17**(1): 1-6. DOI: 10.1258/jtt.2010.100105

[74] Laver KE, Adey-Wakeling Z, Crotty M, Lannin NA, George S, Sherrington C. Telerehabilitation services for stroke. Cochrane Database of Systematic Reviews. 2020;**1**

[75] Beghi E, Gervasoni E, Pupillo E, Bianchi E, Montesano A, Aprile I, et al. Prediction of falls in subjects suffering from parkinson disease, multiple sclerosis, and stroke. Archives of Physical Medicine and Rehabilitation. 2018;**99**:641-651. DOI: 10.1016/j.ampr.2017.10.009