MODULE 2: BIOMECHANICS IN STROKE REHABILITATION

Session 3: BIOMECHANICS AND FUNCTIONAL ASSESSMENT OF BALANCE IN STROKE

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1. LEARNING OBJECTIVES

The objectives of the session are:

- To identify the foundations and physiological basis of normal balance.
- To revise the physiopathology of balance impairment in stroke.
- To describe the tools that can be used to perform an instrumented balance assessment and the parameters provided.
- To describe the foundations of posturography.
- To interpret basic biomechanical data coming from balance assessment.
- To distinguish the typical findings of balance in stroke.
- To recognise the usefulness and applicability of instrumented biomechanical assessment of balance in the field of stroke rehabilitation.

2. INTRODUCTION

A cerebrovascular accident or stroke is a pathology due to the interruption of blood flow to the brain, which causes a set of variable symptoms depending on the affected area. The term stroke refers to the cerebral vascular syndrome that causes a neurological and psychopathological deficit. The pathogenic mechanism common to all strokes is the interruption of tissue metabolism when the vessel is anatomically or functionally interrupted (ischaemia) or breaks (haemorrhage).

Disorders affecting balance or postural control are common after a cerebrovascular accident. Standing balance dysfunction is a limiting stroke sequelae, since the ability to maintain an adequate position in different tasks is essential to perform any activity of daily living in a safe and effective manner. It is important to note that a large group of people with stroke have had at least one fall during the first six months after stroke. A history of falls causes the person to develop a fear of leaving home and to eventually reduce their level of activity.

Postural control is important to improve the patient independence, social participation and quality of life. It is also a fundamental for motor skills and must be considered to determine both the functional and the recovery prognosis, as well as the rehabilitation treatment of the patient with stroke sequelae.

The process of postural control is complex and involves many levels of the body system. All these levels, including those related to cognition, must be studied. The physiological basis, the objective assessment with an instrumental technique, and the most common findings in the analysis of stroke balance are explained below to better understand the pathophysiology of balance in stroke patients. Finally, the usefulness of posturography in rehabilitation is pointed out, showing the results obtained in a clinical case using a posturography system to assess balance.

3. PHYSIOLOGICAL BASIS OF NORMAL AND PATHOLOGICAL BALANCE

The term balance is a physical concept that refers to the absence of forces acting on a body. Human beings are never in perfect balance, but they are always searching for it to maintain a specific position. The standing posture is characteristic of human beings; it is acquired through the sense of their location in space. Human beings are always looking for this balance and, in doing so, the ability of bodies to return to the equilibrium position appears. This property is called stability, a more flexible concept than the physical concept of equilibrium.

To achieve a correct management of balance, standing posture or stability, the central nervous system collects sensory information, processes it and gives responses through muscular activity.

Postural control or standing balance requires a complex interaction of different systems: visual, vestibular, proprioceptive, neural and musculoskeletal system.

The objective of this control is to ensure that the vertical projection of the centre of gravity is within the person's support base. When standing, the support base is represented by the footprints and the area between them. This control requires significant work from the antigravity muscles (gluteus maximus, quadriceps, and surae triceps), and an adequate neuronal regulation through postural adjustments. These adjustments involve a set of agonist/antagonist muscle contractions functionally coordinated to maintain postural balance. Maintaining posture stably in the standing position depends on additional factors, which include the intrinsic strength of the lower limbs muscles and the uniformity of the support surface.

The body is stable only when the ankles, knees and hips are perfectly aligned in relation to the gravitational forces. However, as there are always destabilising forces, the position of the centre of gravity is constantly corrected to keep it balanced, trying to consume as little energy as possible. The body sway caused by these corrections provides an angle that represents the deviation of the centre of gravity of the body with respect to the vertical line that falls over the centre of the support base. This is the theory of the inverted pendulum shown in figure 1.

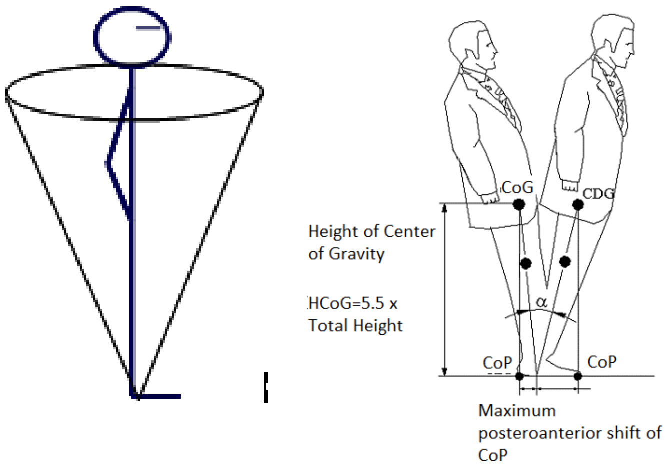


Figure 1. Inverted pendulum model and calculation of the displacement of the centre of pressure according to the height of the person being assessed.

Let's see the physiology of balance in more detail:

Balance control is performed by an elementary circuit that consists of the following systems:

- **Sensory input** for balance control postural. Afferent pathways.
- **Information processing**: central nervous system.
- **Motor outputs** for postural control. Efferent pathways.

Sensory inputs for postural control. Afferent pathways

Three types of sensory information inputs are involved in balance control:

- **Vestibular information**, which activates through the movements of the head with respect to gravity. It detects the gravitational and kinetic forces exerted on the organism, that is, whether the organism is moving or not and its relationship with respect to the force of gravity.

  The vestibular system captures and provides this information. Both the utricle and the saccule are stimulated by linear accelerations and changes in the orientation of the head in relation to gravity, whereas the semicircular canals are stimulated by angular accelerations. This information is regulated in the vestibular nuclei to maintain postural tone, orient the body and its antigravity segments, inform about the head position, and to react quickly to these accelerations.
- **Proprioceptive information**, which activates through changes in the length and tension of the lower limb muscles. They give us an idea of the position of each part of the body in space. For example, when we are in an upward inclined plane, the angle formed between the foot and the leg will be more closed than when we are in a completely horizontal plane.

The proprioceptive factor is especially precise and differentiating, since postural sway produces minimal muscle stretches that correspond to a gain in the response of the muscle spindles. This factor belongs to an important mechanism in the control of the lower limbs, balance and joint damage prevention. According to some studies, these endings are located in the whole limb, not only in the joint.

- **Visual information**, which detects the relative position of the environment with respect to our body. If we take our body as a coordinate centre and move towards a specific object, our vision detects that the distance between that object and our body is decreasing. The basic signal in this system is the movement on the retina of the object that is being watched, which includes slow or fast object following, as well as optokinetic following.

Let's reflect

Have you ever thought why so many sources of input information are necessary to maintain postural control or balance?

Each source of information provides very valuable data, which are incomplete in isolation and therefore could lead to a misinterpretation of the data.

- The technical design of the vestibular system only detects linear and angular accelerations; consequently, when this system does not detect any acceleration, does it mean that the organism is not moving or that it is moving at a constant speed?
- If the proprioceptive system detects a decrease in the angle between the foot and the leg, is the organism on an upward inclined plane or is it that the support surface has suddenly moved backwards?
- If our vision detects that the distance between several objects of the environment and the organism decreases, is it that the organism is moving towards the objects, or the objects are moving towards the organism?

The correct information is obtained once all the inputs of the different systems have been combined. Thus, a correct sensory integration is necessary to readjust and correct any deviation with respect to the vertical. The integration of all this sensory information by processing central information controls balance.

Information processing: Central Nervous System

These inputs or sensory information must be undamaged to maintain balance. The inputs must be permanently processed by the central nervous system (CNS) by using cortical, brainstem and spinal circuits. This processing analyses, selects and compares the sensory inputs that arrive. The cerebellum controls and adjusts the entire system. In general, all the input information is compared with the previous experiences accumulated in order to choose the most appropriate motor response for that situation. When the sensory input does not match any pattern of the "file" (for example, with new experiences, such as travelling for the first time on a ship, or in the case of a vestibular pathology) or when the different sensory inputs conflict (give contradictory information), the motor response of the central nervous system becomes slower and may be ineffective.

To avoid this situation, the central processor is also responsible for selecting the most appropriate input and ignore the input that may lead to errors. In other words, the central processor should not "be fooled". This behaviour learnt over time should be stimulated in the rehabilitation of a person with balance disorders. Central processing is a very dynamic process, constantly alert and always adjusting according the new experiences acquired.

Motor outputs for postural control. Efferent pathways

Once the response has been generated through the central nervous system (CNS), it can be directed:

- Towards the oculomotor nuclei: vestibular ocular reflex (VOR).
- Towards the anterior spinal horns: vestibular spinal reflex (VSR).

Vestibular ocular reflex

This reflex stabilises vision on a fixed object while the head or the body as a whole moves. To do this, it stabilises the image on the retina with the movements of the head by generating an eye movement contrary to head movement. This reflex allows us to see the environment fixed despite head movements.

Vestibular spinal reflex

This reflex is responsible for postural control. It causes the motor response of the nervous system to be sent to the antigravity muscles of the neck, trunk and limbs, through which postural control is performed both standing and moving. The connection between vestibular nuclei and skeletal musculature allows us to adopt a motor strategy in response to a movement or a destabilising force.

Let's reflect

Think about the balance strategy you would use to avoid falling to the ground if you were pushed forward.
Think about what would happen depending on the strength and the direction of the push, or on whether the surface is flat or tilted.
Would you use the same motor response to maintain balance?

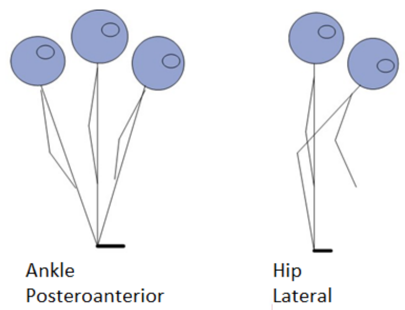
The characteristics of the destabilising force (magnitude, direction), the surface on which we are or the support aids around us can modify our motor response. Motor strategies include plantar flexion of the ankles, taking a step, extending the arms to grab hold of something, or a combination of them. These strategies allow us to maintain the centre of gravity inside the support base and, therefore, to avoid falling. The most common motor strategies are:

Ankle strategy. The movement of the body to maintain balance is performed around the ankle joint, therefore, in the anterior-posterior direction. The movement of the centre of gravity will be slow and far from the stability limits (within the support base). This type of strategy usually occurs when the support surface on which the person stands is stable and bigger than the feet surface.

Hip strategy. A strategy to control balance that acts in all directions, using the hip joint and the inertial forces of the trunk. This hip strategy is used when the ankle strategy is insufficient to maintain balance and when the centre of gravity moves fast towards the stability limits. Therefore, it is used in situations of greater instability, for example, unstable surfaces and/or smaller than the feet surface. The hip strategy generates efforts both in the medial-lateral and the anterior-posterior direction.

Step strategy. This strategy activates when the disturbance is strong enough to really threaten stability. In this case, a gross movement is required, like a jump or a step, to extend the support base so that the centre of gravity remains inside and balance can be recovered.

Several studies have shown that older people or people with balance disorders use the hip strategy more frequently, even when they have their feet on firm ground and/or with an acceptable support base.



> The postural system or balance control depends on an input system that collects information, an integration centre that receives it, discriminates it and generates responses, and an effector system that enables or executes the appropriate responses through motor strategies to maintain posture. Any alteration in these three links can manifest as a postural control or balance disorder.

4. ASSESSMENT: TOOLS AND COMMON RESULTS

Posturography is the most outstanding tool to provide information in balance assessment and it can be used in people with stroke. Although the term includes all the techniques for studying and recording human posture, it is currently used to refer to those methods that analyse postural behaviour when performing the Romberg test using a dynamometric platform.

Through a series of tests, posturography can quantify the functional state of a patient's balance in relation to normal population. It does not provide an etiological diagnosis or the precise anatomical location of an injury, but it evidences the deficiency and determines the patient's compensation strategy. It can assess the importance and severity of the impact of balance disorders on the daily life of the patient; it can also help to establish a treatment and evaluate its effectiveness. This assessment system intends to assess the ability of the subject to integrate the three systems responsible for maintaining posture (vestibular, visual and proprioceptive) and to generate a motor response. Moreover, it isolates and assesses the relative contribution of each system, creating situations of sensory conflict by eliminating or reducing the contribution of the other systems and assessing how the subject behaves in these situations.

As defined by the American Academy of Otolaryngology-Head and Neck Surgery, and the American Academy of Neurology, dynamic posturography is a clinically useful method for studying human balance, which isolates and quantifies sensory and motor contributions to balance control and assesses sensorimotor integration in people with normal and abnormal sensorimotor skills. The American Medical Association has recently included posturography as a method for documenting deficits and disabilities. Nowadays, dynamic posturography is considered the "gold standard" for studying postural control.

Posturography can assess the imbalance of a patient. This system does not replace a good anamnesis and a physical examination, but it complements them together with other screening tests that can be used according to the diagnosis. It also identifies rehabilitation patterns and monitors progress. Posturography helps to plan the treatment and to monitor its effectiveness. Since it provides the level of functional adaptation achieved by the patient to the injury or pathology, a more precise therapeutic programme can be designed. The results help to select the most appropriate treatment and to monitor its effectiveness.

Some basic concepts about balance and postural control are explained below to better understand the methodology followed in balance assessment using posturography.

- **Displacement of the centre of pressure.** It is the movement, recorded by the dynamometric platform, of the vertical projection of the centre of gravity (CoG). It corresponds to the postural sway without changing the support base (Figure 2).
- **Support base.** Contact area between the bottom of the feet and the ground surface. If the support base is increased (the feet separate), stability increases because it helps to maintain the centre of gravity of the person within this area.

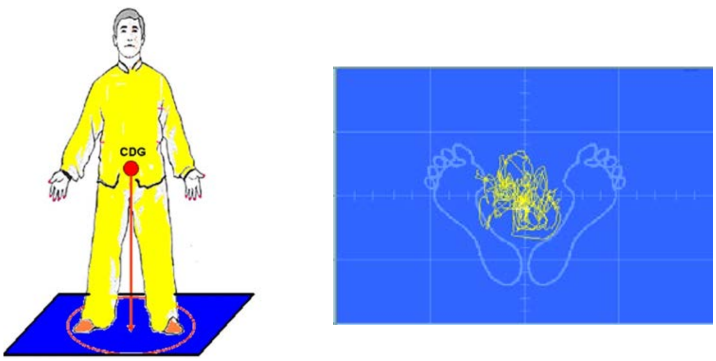


Figure 2: Recording postural sway using a dynamometric platform. It represents the movement of the vertical projection of the centre of gravity when standing inside the support base.

- **Movement strategy to maintain balance**. Type of movement performed to maintain the vertical projection of the centre of gravity inside the support base. There are three types of strategy (already explained in the previous point): the ankle, the hip and the step strategy. The selection of one strategy depends on the degree of displacement of the centre of gravity in relation to the stability limits, the displacement speed, and the support surface on which the person stands. People without any deficit in postural control or balance normally uses the ankle strategy for stable surfaces and, as the support surface becomes more unstable, they include the hip strategy in their movement. Moreover, people with balance problems use more the hip strategy than people with good balance.

- **Stability limits.** Maximum distance that a subject can move her or his centre of gravity without changing the support base, that is, without moving the feet off the ground. These limits basically depend on the location of the feet, the support surface, the age and the height of the subject.

Posturography uses a **dynamometric platform** as measuring instrument. This tool is sensitive to the horizontal and vertical forces to which it is subjected and therefore can measure the displacement of the centre of pressures (vertical projection of the centre of gravity) and postural sway. This tool is connected to a computer system that shows the coordinates of the centre of pressures, which represents a good estimate of the position of the centre of gravity when the body sways. On the basis of these coordinates, it is possible to represent the movement of the centre of pressure, as well as to provide different parameters, such as the area of the surface described by the movement of the centre of gravity, the speed of the displacement (distance per unit of time) or the vector force dominant position, among others.

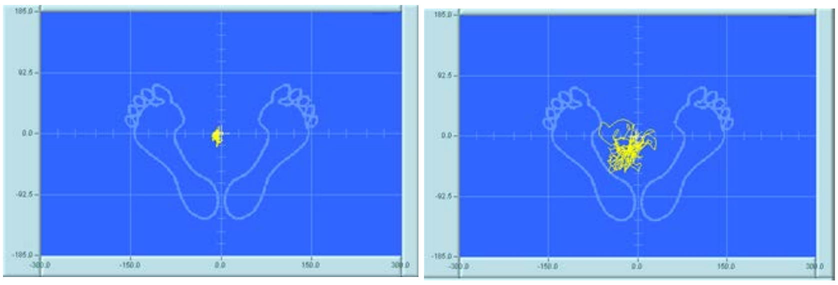


Figure 3. **Left**: recording of the displacement of the centre of pressure of a person with stable balance. **Right**: recording of a more unstable person. The displacement or sway of the centre of pressure is greater.

The **objective** of an instrumented **balance assessment** is to detect functional alterations when maintaining the standing position and to analyse the response of postural control when the sensory inputs (visual and proprioceptive information) that help to achieve balance are altered. This test assesses the patients control in the displacement of their centre of gravity during a series of tests performed standing.

Posturography can be static or dynamic. **Static posturography** is the technique that uses a fixed dynamometric platform that measures the **postural sway** of the subject during a Romberg test by recording the movement of the centre of pressure. Currently, the most common combination of tests is to integrate several Romberg-type tests (eyes open and closed) with somatosensory interference (placing the person on a foam rubber) (Image 4 left).

Dynamic posturography uses a dynamometric platform mounted on a support that can be moved horizontally, tilted forwards or backwards and/or rotated around an axis that is collinear with the ankles. In some cases, the movement is coupled to that of the subject in order to maintain a constant ankle angle, thereby reducing the information from this joint's proprioceptors; they can also be surrounded by a visual environment designed to disorient the subject. This system was developed by Nashner in collaboration with Black (Image 4 right).

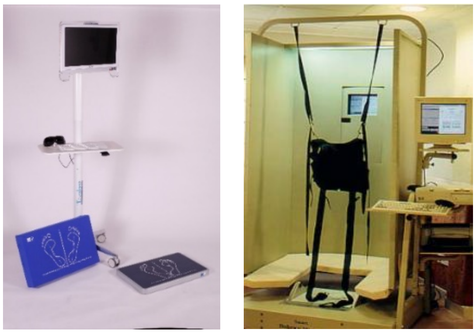


Image 1. **Left**: Static posturography: Evalanz (IBV). **Right**: Dynamic posturography: Smart Balance Master (Neurocom)

Generally, the most used measurement method **in balance assessment is divided in two parts**:

- Sensory organisation test
- Stability limits test

NOTE: The video related to the session shows the protocol applied to a patient with left hemiparesis after stroke.

Sensory organisation test:

This test analyses the contribution of the different sources of sensory information involved in maintaining balance, and the strategy of the patient. During the test, the patient remains static, standing on a dynamometric platform while postural sway is recorded in different measurement conditions. The strategies used to alter sensory information include closing the eyes and/or using unstable surfaces like foam or moving the platform or the environment. In all these tests, posturography records postural oscillations by measuring them and comparing the results with those of people without balance disorders (degree of instability) and comparing the results in different conditions (sensory quotient).

In the case of **static posturography**, balance is assessed in the following conditions (R: Romberg):

1. Test eyes open (normal vision), fixed platform and visual environment (REO).
2. Test eyes closed (absence of vision), fixed platform (REC).
3. Test eyes open (normal vision) with unstable support surface or foam(RFEO).
4. Test eyes closed (absence of vision) with unstable support surface (foam) (RFEC). See Image 2.

Dynamic posturography adds the following tests to the previous ones, since the platform on which the patient stands is surrounded by a visual environment and both can move in isolation or simultaneously.

5. Test eyes open (normal vision), mobile visual environment proportionally adjusted to the anterior-posterior angle of body sway, fixed platform.
6. Test eyes closed (absence of vision), mobile platform associated with postural sway.
7. Test eyes open (normal vision), mobile platform and visual environment associated with postural sway.

The duration of each test may change depending on the measurement equipment used. They usually last between 20 and 30". During the tests, the patient is told to be as still as possible on the platform despite the artificial disturbances applied.

Image 2. Test eyes closed (absence of vision) with unstable support surface (foam) in a static posturography test: RFEC.

Stability limits tests:

This test records the voluntary control of the subject, who is in the standing position, to place her centre of gravity on or close to her stability limits. The results of this test allow us to know the area where the patient can move her centre of gravity without falling. During the assessment, the patient can see her centre of gravity reflected on the screen of a computer in front of him or her. The patient must move it without moving the support base towards the targets reflected on the screen, which represent her theoretical stability limits according to age and height. This test assesses the stability limits beyond which a fall can occur. That is, how far she can move her centre of gravity without falling.

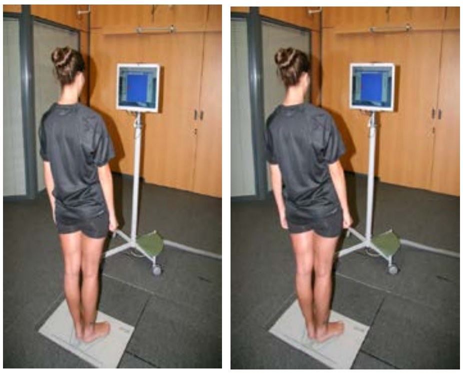


Image 3. Test to assess the limits in which the centre of gravity moves from the centre to the left.

Posturography results:

The results most frequently used in posturography for the assessment and subsequent rehabilitation of balance include:

Degree of stability

The degree of stability or **level of balance** provides information on the patient's stability (information on the postural sway or oscillations of the patient compared with a pattern of people without balance disorders) in conditions of sensory conflict. The result is usually shown as a non-dimensional percentage. Values close to 100% indicate minimum sway and therefore good stability. As these values move away from 100%, instability increases. The further from that value, the greater the risk of falling (Figure 5 left).

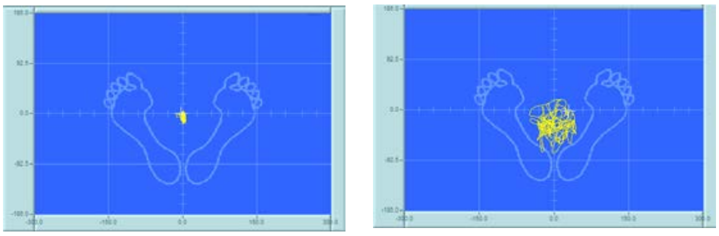


Figure 4. Posturography recording: displacement of the centre of pressure. Left: minimal sway. Good stability. Result: 100%. Right: greater sway, worse stability. Result: 60%.

Each equipment has normal or reference values implemented; therefore, the results in terms of normal or pathological cannot be compared to posturography devices from other companies.

Sensory analysis

This information helps us to interpret sensory patterns. The result expressed as indices characterises the differences between the measurement condition 1, that is, test with eyes open (normal vision), fixed platform and visual environment, and the assessment of stability obtained in the individual conditions in which the sensory information was altered (figure 5 right). This analysis provides the following indices:

Somatosensory index

It refers to the patient's ability to use somatosensory references. A result close to 0 or below the reference limits of the measuring equipment means that the patient is less stable with eyes closed than with eyes open on a fixed surface, which indicates an alteration in the somatosensory integration.

Visual index

It refers to the patient's ability to use visual references or information. A low result or a result below the system reference limits indicates that the patient becomes unstable on uneven or unstable surfaces.

Vestibular index

It refers to the ability to use vestibular information. A low ratio occurs in patients who become unstable in conditions of irregular support and visual input cancelled.

Visual preference index

Some systems also have a visual preference index or ratio that provides information about the degree of balance support in visual references. Values lower than the reference data indicate that the person is unstable in a moving visual environment.

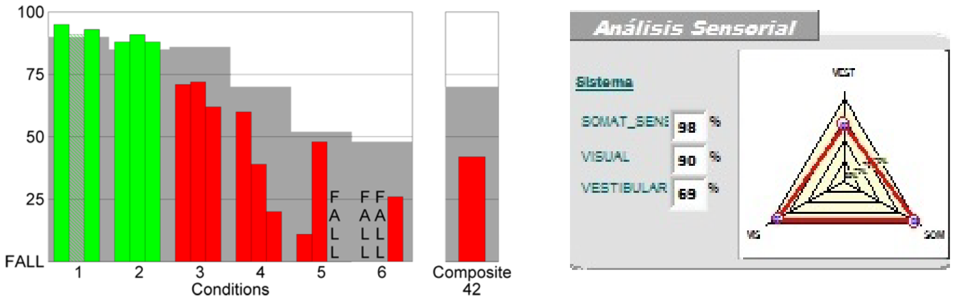


Figure 5. Graphic representation of the results of a sensory test. **Left**: results obtained in each repetition of the 6 tests and their average value (Composite) using a Neurocom **dynamic posturography** (the normal results are displayed in green and the pathological results in red.) The grey line in the background is the limit of normality. **Right**: representation of the patient's ability to use each information input involved in the maintenance of balance using a system of **static posturography**: vestibular (VEST), somatosensory (SOM) and visual (VIS) index. The further the red line is from the edges of the figure, the worse the balance is.

Strategy analysis

Posturography can also quantify the use of ankle and hip strategy. As the difficulty of the test increases (from 1 to 4 in static posturography and from 1 to 6 in dynamic posturography), the patient goes from using only the ankle joint (anterior-posterior displacement) to increasingly using the movement of the hip joint (medial-lateral displacement).

Stability limits

A graphic display shows the stability limits of the person in relation to a normal pattern (Figure 6 and 7). In addition, it provides information about the reaction time of the patients to start moving their centre of gravity, the speed at which they move it, the maximum distance they can move it without falling, and the ability to control the displacement of the centre of gravity, which is determined by the straightness with which it moves towards each target. At the end, a total result for each limit is obtained.

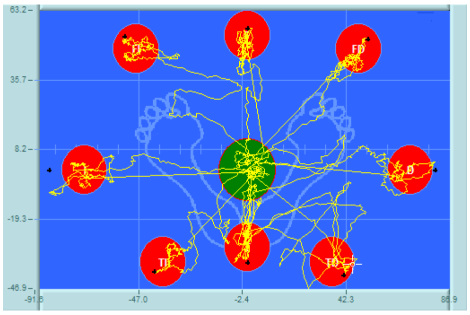


Figure 6. Graphical display of the voluntary displacement of the centre of gravity during the limit test. The red targets represent the normal theoretical limits that should be reached for the patient considered.

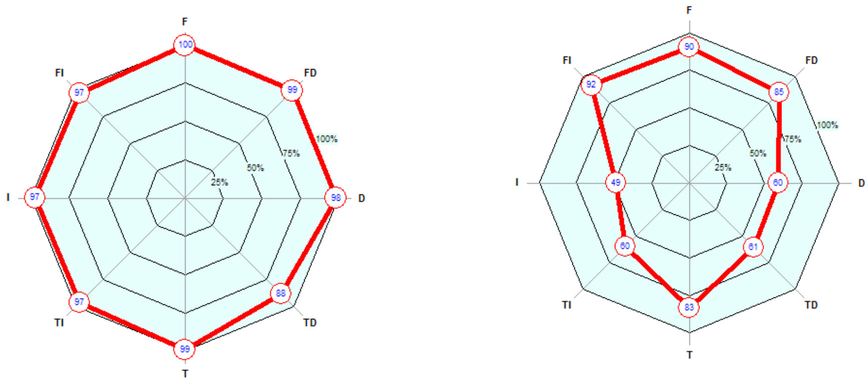


Figure 7. Graphical representation of the results of the limit test. **Left:** normal limits result. **Right**: decrease in the lateral and rear limits.

5. PHYSIOPATHOLOGY OF BALANCE IN STROKE. TYPICAL FINDINGS IN PATIENTS WITH STROKE

After a stroke, patients may present several sensory and motor disorders that affect balance, which include muscle weakness, impaired motor control, decreased flexibility of soft tissue, muscle tone alteration, sensory disorders and cognitive deficits. All these deficits result in a loss of both coordination and of the sense of being well balanced, and, therefore, in an increased risk of falling.

If this problem is analysed in more detail, we find that the inability of the stroke patient to generate adequate strength, mainly in the lower limbs, affects the ability to maintain the support and the body weight, as well as gait. Along with the problem of muscle weakness, the person shows lack of coordination of agonist/antagonist muscles as well as coordination among the muscles of different parts of the body. This lack of coordination affects both starting and maintaining the movement and generates an incorrect visual/vestibular information due to the position deficit of both lower limbs with respect to the trunk/head. The delay in starting muscle activity and the slowness in generating force affects both the preparation for an imminent stability alteration and the speed of the response to the loss of balance. All these aspects affect the balance of a person with stroke.

Furthermore, the secondary muscle adaptations observed after stroke, such as changes in length and stiffness, also affect muscle activation, the speed and accuracy of the response to small disturbances and, therefore, balance. For example, after stroke, the mobility of the ankle joint is usually limited because of the spasticity or reduced elasticity of the soft tissue and muscle shortening.

Vision, as seen in the previous section, is also important to control balance. It provides information about the location of the body in relation to the environment that surrounds it and, therefore, it makes it possible to predict the approaching balance disturbances. Additionally, somatosensory input is also important for both support and gait. Thus, the dysfunction caused by stroke due to the neurological pathway injury also affects the sensory and cognitive/perceptual system (hemineglect), which affects the ability to maintain balance by altering sensory information in its physiologic process.

It should also be noticed that focusing the attention on two or more tasks represents a challenge for many stroke patients, which poses in turn a problem in maintaining balance.

In general, stroke patients adapt worse to situations that generate a balance conflict than healthy people. In addition, they do not know how to distinguish the sensory stimuli that give them safety and trust in both static and dynamic. They need more attention to maintain balance and they do not know what strategy to use to respond to these disturbances because of their cognitive disorder.

6. BIOMECHANICAL BALANCE PATTERNS IN STROKE: EXAMPLE

Studies using posturography in stroke patients show that these patients adapt worse to changes in balance disturbances. In order to perform a balance assessment test using posturography, the person needs to have a specific minimum functional level. This level should allow the patient to stand on a narrow support base for a minimum period of time (at least 20¨). Therefore, a complete balance assessment in stroke should integrate functional scales and objective measurement tools such as a dynamometric platform used in posturography. When the patient cannot meet the specifications of the instrumental technique protocol (floor effect), clinical scales (ceiling effect) will be used. When the patient reaches these specifications in the measurement protocol, instrumental techniques will also be used in the assessment process. The combination of clinical scales with posturography or quantitative instrumental techniques in general, improves the understanding of both postural alterations and the functional status of the person.

Posturography has a significant floor effect, since it can only be performed on patients who can stand for a specific period of time; however, it has no ceiling effect.
The ground effect of posturography is compensated by simple clinical scales; however, clinical scales have a ceiling effect when the patient has almost completely recovered

balance, losing sensitivity to small changes and on more functional patients. Posturography can be a good instrument to compensate for the ceiling effect of clinical scales.

In the assessment protocol, the most widely used tests to objectively assess balance using posturography in stroke patients are the tests with eyes open (normal vision), fixed platform and visual environment, as well as the tests with eyes closed (absence of vision), fixed platform. These tests are followed, although with some difficulty, by the test with eyes open (normal vision) with an unstable support surface (foam). In any case, the functional recovery of the person determines whether or not to add more difficult assessment tests. The objective results of posturography are very useful to make such decision.

Objectively, balance in stroke patients and their consequent hemiplegia is characterised by two aspects: the increase in postural sway during the static standing position and an asymmetric distribution of the body weight, with less weight supported in the paretic side.

In relation to this information, posturography findings in studies about stroke show:

Postural sway:

When analysing the postural oscillations in people with stroke, studies focus on the magnitude of displacement of the centre of pressures, the average speed of the displacement, the maximum displacement in the anterior-posterior axis, and the maximum displacement in the medial-lateral axis.

The tests performed show an increase in the displacement of the centre of pressure during standing compared to healthy people. This increase in sway is related to an increase in the body sway to maintain postural control. As the difficulty of the tests increases and, therefore, the disturbances on the subject increase, the oscillations are greater because of the lower capacity of postural control. The greater the postural sway, the greater the instability. In addition, the variability of these postural oscillations decreases as the ability for postural control increases. There is also a lateral displacement towards the non-paretic limb due to the lack of control over it.

It is worth mentioning the role of the cognitive control of the stroke patient in the measurement of sway. If this factor is cancelled by performing a dual control task (for example, keeping as still as possible while performing a mental calculation), postural oscillations increase. This means that, in order to maintain balance, the person with stroke focuses on it and gets better control. If this ability to concentrate is eliminated, postural sway increases.

Sway in the different axes:

The results regarding the displacement of the centre of pressure in the anterior-posterior and the medial-lateral axes are variable. These maximum displacements decrease over time, as postural control improves, but the medial-lateral displacement is the one that seems to be more constant in time. The reduction in the displacement in the anterior-posterior axis in the tests with eyes open (normal vision), fixed platform and visual environment, is important because some authors relate the increase in this parameter with the risk of falling in older people. The weakness of the abductor muscles is suggested as responsible for postural instability in the frontal plane, and the weakness of the plantar flexor muscles with instability in the anterior-posterior plane.

Sensory indices:

The difference in the displacement of the centre of pressure of healthy subjects and patients with stroke is reduced in the test with eyes open (normal vision) with an unstable support surface (foam), which means that patients are developing a visual dependence. When the visual information is removed (eyes closed), the differences in the sway speed of the centre of pressure increase compared with healthy subjects. However, when balance depends only on the visual information (when the somatosensory information is cancelled using foam), the differences between healthy patients and stroke patients decrease because patients with stroke have learned to "rely" on their visual information.

In the test with eyes open on unstable surface, somatosensory information is altered, consequently, the patient with stroke loses much of the sensory information, which makes it more difficult to perform this test. If the test is performed with eyes closed (cancelling visual information) with an unstable surface (alteration of the somatosensory information), the balance of the subject depends only on the vestibular information. Some authors describe the difficulty that stroke patients have in using vestibular input correctly in the chronic phase. It is also important to note that several studies on people with stroke and impaired balance show that these patients depend too much on visual information to stay stable. Therefore, it is necessary to create rehabilitation programmes for the patient to progressively learn how to use more somatosensory and vestibular input.

With respect to stability limits and control of the centre of gravity, some works show that, in a static (sensory) test, patients have a tendency to lean towards the paretic side, whereas, in the analysis of stability limits, they show difficulty in moving their centre of gravity towards the paretic side voluntarily and in a controlled way.

The results of the balance assessment using an instrumental technique (Posturography Evalanz/IBV) are shown and commented on below. The video associated to this session offers a more detailed explanation.

Clinical case

The patient is a 59-year old man. Right dominance in upper and lower limbs.

Current condition:

The diagnosis is right ischemic pons stroke in May 2013. The main clinical signs included left hemiparesis with dysarthria and left deviation of the mouth. He performed a comprehensive rehabilitation treatment focused on the recovery of deficits during the inpatient stage and continued on an outpatient basis until he was discharged due to stabilisation.

He is currently in the stabilisation and sequelae phase. Presents left hemiparesis predominantly distal. Autonomous crutch-assisted ambulation indoors and outdoors, although he can walk without any aids short distances. He uses an ankle foot orthosis (dictus) at left foot. Superior functions not involved, language preserved in form and content, although some behavioural changes and emotional lability are observed after stroke. No current swallowing disorders (oropharyngeal dysphagia occurred with liquids in the acute phase, currently resolved). Clinical signs compatible with neurogenic bladder/urge urinary incontinence; spontaneous urination; no faecal incontinence. Mostly independent for most of the BADLs, although he needs assistance when dressing (buttons, shoes etc.), using the bathroom (adapted shower), grooming and eating (he uses the right hand for the spoon and fork, and needs help from another person to use knives or cutting food).

Physical examination before the biomechanical assessment:

Preserved, fluid and coherent language; no dysarthria. Slightly reiterative speech. Left supranuclear facial paralysis. Preserved extraocular movements with mild limitation of extreme vertical gaze. No nystagmus objectified. No confrontation hemianopsia or gross visual field deficits.

Visual gait analysis (without ankle foot orthosis and without crutch): paretic gait with a steppage pattern. Forefoot initial support, increased knee flexion and early hip flexion in terminal stance and pre-swing phase; excessive ankle plantar flexion during gait, although no objective dragging. He maintains upper left limb in flexor synergy, no arm swing.

Mild increase in tone with spasticity grade 1 to 1 at elbow and knee level. Spastic left hand with tendency to claw fingers; thumb not clenched. It is completely reduced passively. Indifferent left plantar reflex, right Babinski sign. No Achilles or patella clonus.

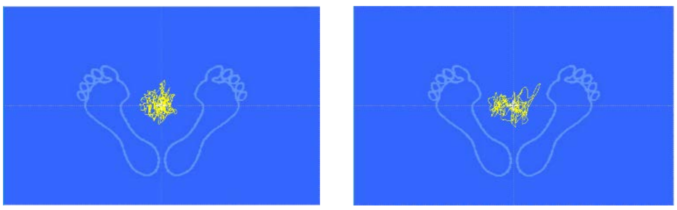
Left hemiparesis with distal predominance in the upper limb and shoulder abduction 2/5 (not complete contragravity), flexion-elbow extension and wrist extension at 4-/5; distal at 2/5 (he starts motion against gravity, he does not complete gripping or extend fingers completely, no functional pinch). Lower limb paresis also predominantly distal (ankle dorsiflexion at 2/5 with plantar flexion at 4/5).

- A **functional assessment of the postural balance ability** was performed with the **EValanz/IBV system**, which assesses static stability using a dynamometric platform and compares it with databases of subjects with a normal function, segmented by height, age and gender.

Results of the sensory assessment

REO

REC



RFEO

RFEC

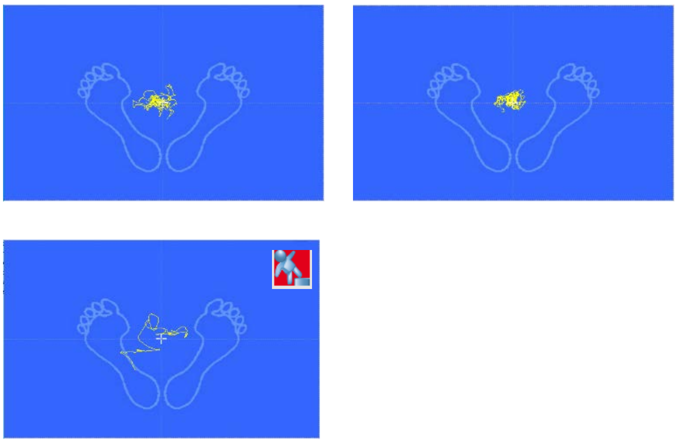


Figure 8: Displacement of the centre of gravity (**postural sway**) in the medial-lateral and anterior-posterior direction during the Romberg tests. Fall (the patient cannot maintain balance).

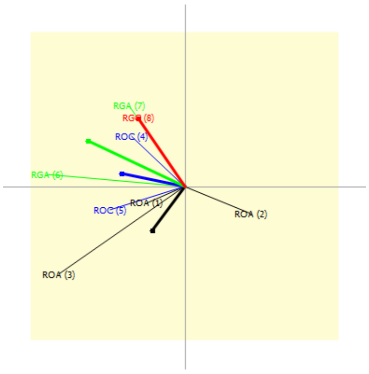


Figure 9. Representation of the **displacement vectors** for each Romberg test performed. Displacement to the left side of the patient.

Sensory

Test	Assessment		Repeatability	
Romberg Eyes Open (REO)	81	%	39	%
Romberg Eyes Closed (REC)	71	%	52	%
Romberg with Foam Eyes Open (RFEO)	87	%	36	%
■ Romberg with Foam Eyes Closed (RFEC)	0	%		%
Sensory (SENS)	79	%	42	%

■Test with fall

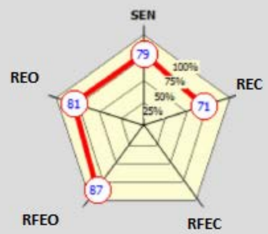


Figure 10. Result of the assessment expressed as a percentage of normality and repeatability of the different

Romberg tests. Values lower than 90% in the assessment are considered not normal or functionally altered, except in RFEC, where it is 85%.

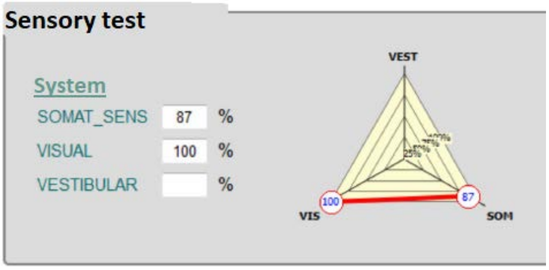


Figure 11. Result of the **sensory indices** expressed as a percentage of normality. Values lower than 95% are considered not normal or altered.

Figure 12. **Final result of the sensory assessment test**. Values lower than 90% are considered a balance disorder.

Clinical interpretation of the results of the sensory analysis:

Stability is altered with respect to normal values in all the Romberg tests performed (the postural sway recorded by the dynamometer platform). Both the Romberg test with eyes open and the Romberg test with foam and eyes open show a mild alteration or instability. The Romberg test with eyes closed shows the greater instability and, therefore, alteration, which is compatible with visual dependence, since by removing this information the ability to maintain static balance is more dramatically altered. Additionally, the patient has not been able to perform the Romberg test on foam with eyes closed and fell during his attempt.

These findings are compatible with a pattern of central involvement, in which there is a disorder in the integration of inputs and in the implementation of the appropriate compensation mechanisms for each case in a reflex manner. For this reason, the patient cannot maintain balance in more difficult conditions.

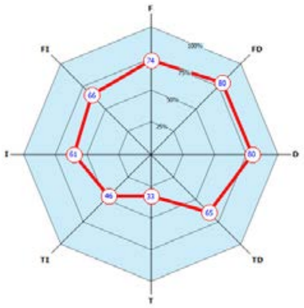
A pattern of visual dependence stands out, with a pattern of vestibular involvement of central origin (when external sensory inputs are cancelled or interfered, the vestibular system is not able to make up for this information deficit). Besides, the somatosensory index obtained, which refers to the patient's ability to use sensory input, was 87%, (values below 95% are considered altered for this index). This low score means that the patient is less stable with eyes closed than with eyes open on a fixed surface, which indicates an alteration in the integration of somatosensory information. The result is shown as a percentage of normality.

The force vector (see Figure 9) shows a displacement tendency towards the left side, which is generally repeated in all measurement conditions. This displacement coincides with the deficit in the motor, sensory and voluntary motor control that affects this hemibody, for which the appropriate compensation mechanisms to avoid displacements of the centre of gravity towards that side is pathological.

The repeatability of the results of the different tests performed has been low. However, this is feasible in the neurological pattern shown by the patient.

With a total score of 79% (scores below 90% are considered not normal or altered) in this test, the patient ability to maintain static balance is considered altered.

Results of the stability limits



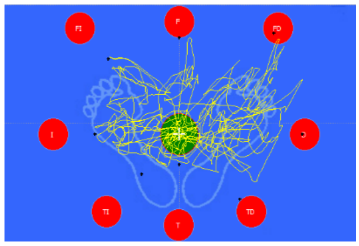


Figure 13. **Left**: graph of the limits of stability and value of the result as a percentage of normality for each target. **Right:** displacement strategy of the centre of pressure (yellow line) in the stability limits test.

Clinical interpretation of the stability limits:

The result of the voluntary displacement of the centre of gravity towards normal stability limits (those obtained from a normality pattern segmented by age, gender and height) was altered (63% versus the limit considered normal: 85%). This result translates into a reduced area of stability, beyond which instability significantly increases, and there is a risk of falling. It should be noted that the decrease is more noticeable in the rear left limit and the rear limit, where the patient compensation mechanisms are more altered. To compensate for this, the patient will tend to increase his support base both in static and during gait.

Result and final interpretation of the balance assessment

Average Assessment
MEAN 77 %

Figure 14. Final result of the **balance** assessment. Values lower than 90% in the Global are considered not normal or functionally altered.

From the functional point of view, the final result of the test (77% in the Global assessment) translates into a **functional alteration in postural control or an impaired balance**. The findings are compatible with a pattern of central affectation, in which there is a disorder in both the integration of inputs and the implementation of the appropriate compensation mechanisms in each case in a reflex manner. Consequently, in conditions of greater difficulty, the patient is not able to maintain balance. In addition, this pathologic pattern causes a decrease in the stability limits within which the patient is able to move his centre of gravity safely, especially backwards and to the left, which corresponds with the affected hemibody.

7. USEFULNESS OF INSTRUMENTED BALANCE ASSESSMENT & POSTUROGRAPHY IN STROKE REHABILITATION

An impaired balance hinders the global functional recovery of the patient mainly because it affects the recovery of the walking ability. Achieving a proper postural control standing is a prerequisite for ambulation and can be used as a sign of good prognosis for functional recovery after stroke. Indeed, postural control is the best predictor of independence.

Restoring the postural and motor control of ambulation, as well as the activities related to them, is one of the main objectives of rehabilitation in the subacute phase of a person with stroke. In the chronic phase, the main objective is to maintain the level of functional independence achieved in the previous phase and, if possible, to work on improving it as much as possible. Another goal is to avoid falls and thus fractures due to lack of balance. These goals of the treatment show the importance of restoring postural control in these patients, and the usefulness of posturography as an instrumental technique to help reach these objectives and to monitor patients' progress during the rehabilitation process. Individualised rehabilitation using posturography might provide satisfactory results in a large number of cases (Figure 15), but we should not forget that it is part of a general process of stroke rehabilitation.

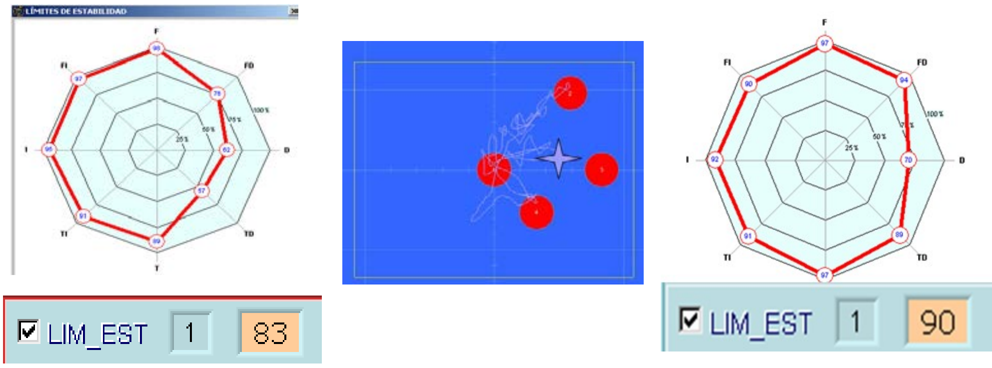


Figure 15. Left: assessment of stability limits. Result: 83%. Limitation on the right stability limits. Central: test of rehabilitation exercises using visual feedback, promoting the displacement of the centre of gravity towards the deficit side. Right: post-treatment assessment. Result: 90%. An important improvement is observed.

The interest of posturography for the rehabilitation treatment of balance disorders in stroke patients lies in the objective information that it brings. This information is very useful for designing a tailor-made rehabilitation programme adapted to the specific deficits of the patient. Posturography provides assistance in treatment planning and helps to control its efficacy.

The objectives of a rehabilitation using posturography are:

1. **To promote postural stability** in those conditions that have shown a deficit. For example, if the sensory analysis records a pattern of visual dependence, which is common in stroke, the rehabilitation will focus on making the patient use vestibular stimuli as much as possible on uneven surfaces, mobile platforms and in situations of visual conflict (moving or distorted images).
2. **To correct the misused strategy** of postural control, which is important for the person to know how to choose the most appropriate balance strategy to maintain balance in conflictive situations. If hip strategy predominates, small balance disturbances will cause

the subject to use large hip and trunk movements, which implies spending a lot of energy to maintain balance. In the end, this not very an effective strategy and limits the patient balance capacity. Thus, by means of posturography, exercises to promote the use of other strategies (mainly ankle strategy) might be performed.

3. **To correct the misalignment of the centre of gravity** and increase the limits of stability using visual feedback techniques that will allow patients to develop a self-perceived stability, to know their limits and the result of their movements.

The usefulness of posturography in rehabilitation is based on the objective information that it provides in relation to the **degree of dysfunction or instability**, about the degree or level of functional impairment, correlating the results with the subjective state of the patient. In addition, the use of biofeedback techniques for rehabilitation are shown to be helpful. Besides, the results provided by posturography are easy to explain to the patients and/or their relatives, which allows them to participate in the process. The results obtained help both the doctor and patients to know their condition, to understand the symptoms and the consequences in their daily life, and to work on either improving them or learning how to compensate them. The results also help to select the most appropriate treatment and to monitor its effectiveness.

8. KEY IDEAS

1. Standing balance dysfunction is a very limiting consequence of stroke, since the ability to maintain proper posture in different tasks is essential to perform any activities of daily life safely and effectively, and interferes with the performance of a functional gait.
2. The process of postural control is complex and involves many levels of the body system. Postural control depends on an input system that collects information, an integration centre (central nervous system) that receives this information, analyses it and generates a motor response, and an effector system that enables adequate responses to maintain posture. Any alteration in these three links can manifest as an impairment in postural control.
3. The process of balance assessment in the context of stroke should consist of functional scales and objective measurement tools such as the dynamometric platform used in posturography. Posturography analyses postural sway standing.
4. Objectively, balance in patients with stroke and the consequent hemiplegia is characterised by an increase in the postural sway during the static standing position and by an asymmetry in the distribution of the body weight, with the paretic side supporting less weight.
5. Posturography allows us to design an individualised treatment for postural control and to make a more objective follow-up of the functional status of the stroke patient.

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