BALANCE ASSESSMENT USING COMPUTERIZED STATIC POSTUROGRAPHY

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ABSTRACT

Equilibrum is a complex process. Combined visual, somatosensory and vestibular inputs are required in order to maintain the body balance. Any dysfunction in one of these channels may lead to vertigo and imbalance. Computerized static posturography can be used to assess the contribution of these sensory channels in the patient's balance, calculating each sensory coefficient (visual, somatosensory, vestibular).

Key words: balance, computerized static posturography, visual, somatosensory, vestibular inputs

BACKGROUND

After headache, vertigo and dizziness are among the most frequent presenting symptoms, not only in neurology.

Equilibrum is a complex process. Combined visual, somatosensory and vestibular inputs are required in order to maintain the body balance. Any dysfunction in one of these channels may lead to vertigo and imbalance.

Balance is a complex process involving coordinated activities of multiple sensory, motor and biomechanical components. The position of the body in relation to gravity and the surrounds is sensed by combining visual, vestibular and somatosensoty inputs. Balance movements involve motions on the ankle, knee and hip joints, which are controlled by coordinated actions of ankle, tight and lower trunk muscles.(1)

BIOMECHANICS OF BALANCE

To balance with the feet in-place, the position of the body's **center of gravity (COG)** must be maintained vertically over the base of support. In this condition, the person can resist the destabilizing influence of gravity and actively move the COG. If COG is positioned outside the perimeter of the base of support – the person has exceeded the limits of stability. (2,3,4)

Center of gravity sway – the angular displasment of COG from the gravitational center – is defined as the angle formed by the intersection of a first line from the center of the base of support through the COG and a second line extending vertically.

The base of support for standing on a flat, firm surface is defined as the area contained within the perimeter of contact between the surface and the two feet. The base of support is nearly a square when the feet are placed confortably apart when the person is quietly standing.

The limits of stability (LOS) defines the maximum possible COG sway angle in antero-posterior and lateral dimension. The LOS perimeter can best be described as an ellipse – the dimension antero-posterior is approximatively $12,5^0$ from the backwardmost to the forwardmost point and the laterak dimension is approximatively 16^0 from the left to the rightmost points. (5,6)

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Limits of sway is a two-dimensional quantity (antero-posterior and lateral) defining the maximum spontaneous COG sway angle. A person attempting to maintain balance spontaneously sways back and forth and from side to side. The limits of sway is alaways well within the LOS.

Center of gravity aligment – is a point at the center of the area contained within the limits of sway perimeter. When a normal person is asked to stand erect, COG aligment is placed accurately above the center of the base of support. When COG is aligned over the center of the base of support, the limits of sway can be as large as the LOS.

The LOS depends on the placement of the feet and the base of support, but also depends on **COG sway frequency**. When COG sway is **slow** (last 2 to 3 seconds or longer – front to back or dside to side) – COG movements within the full range of LOS are possible. When a sway oscillation is completed in 1 second of less, the LOS contracts to approximately 3^{0}., *higher frequency reduce the effective LOS*. (7)

Equilibrum – is reached when the center of gravity is projected in the area of the base of support (the 2 plantar surfaces and the area between them).

SENSORY CHANNELS IN MAINTAINING BALANCE

Sensing the position of the COG relative to gravity and the base of support requires a combination of visual, vestibular and somatosensory (tactile, deep pressure joint receptor and muscle proprioceptor) inputs.

Vision mesures the orientation of the eyes and head in relation to surrounding objects. Somatosensory inputs provide information on the orientation of the body parts relative to one another and to the support surface. The vestibular system measures gravitational, linear and angular accelerations of the head in relation to inertial space.

The somatosensory input derive from the contact forces and motions between the feet and support surface. It is the dominant sensory input to balance under normal (fixed) support surface conditions. (8-12)

The visual input plays significant role in balance, especially when the support surface is unstable. COG sway is significantly less with eyes open than with eyes closed. The stabilizing effect of vison is illustrated by comparing eyes open and eyes closed sway while a person stands on a compliant foam rubber pad. (13-15)

The somamtosensory and visual inputs are more sensitive to body sway than the vestibular system. **The vestibular input** allow independent and precise control of head and eye positions**.** Vestibular input is critical for balance when somatosensory and visual inputs are misleading or unavailable. (7, 16-18)

COMPUTERIZED STATIC POSTUROGRAPHY METHOD

Computerized Static Posturography (CSP) is a quantitative method for assessing upright balance function under a variety of tasks that effectively simulate conditions encountered in daily life.

The National Institute for Research and Development for Fine Mechanics (INCDMF-CEFIN) elaborate a static posturograph (research grant – Quality and Standards Programme CALIST – partners INCDMF, University Hospital Bucharest, Institute) – ECHOM MODEL ("Echipament electronic pentru controlul echilibrului uman"). (Figure 1)

The typical forceplate consist of a flat, rigid surface supported on three or more points by independent force-measuring devices.

As the patients stands on the forceplate, the vertical forces recorded by the measuring devices are used to calculate the position of center of the vertical forces exerted on the forceplate surface over time. The center of vertical force movements themselves provide an indirect measure of postural sway activity.

The forceplate can also measure the horizontal shear forces exerted by the patient's feet against the support surface. Horizontal shear forces measure accelerations of the body COG in the antero-posterior and lateral directions.

The forces measured by the forceplate are recorded and transformed by specials softwares in equilibrium parameters and scores. (19)

EQUILIBRUM SCORES

Equilibrum score is a nondimentional percentage which compares the patient's peak amplitude of sway (antero-posterior and lateral) to the theoretical limits of stability (LOS).

The patient's theoretical LOS is the maximum forward and backward center of gravity sway angles that can be achieved by a normal individual – for antero-posterior direction.

The patient's theoretical LOS is the maximum left to right center of gravity sway angles that can be achieved by a normal individual – for lateral direction.

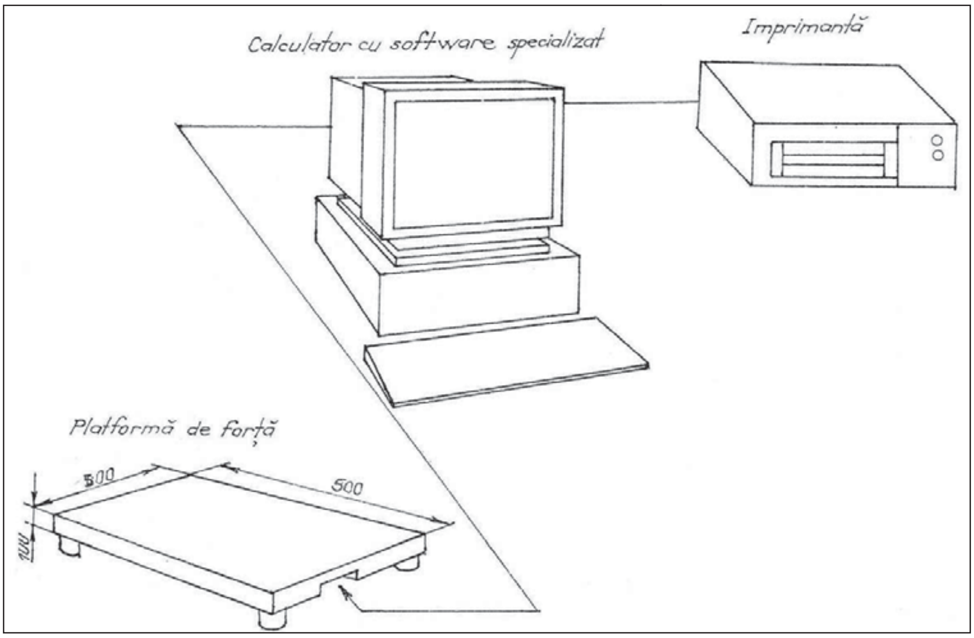

FIGURE 1. *Computerized Static Posturography (CSP) - The National Institute for Research and Development for Fine Mechanics (INCD-MF-CEFIN) (research grant – Quality and Standards Programme CALIST – partners INCDMF – CEFIN, University Hospital Bucharest) – ECHOM MODEL ("Echipament electronic pentru controlul echilibrului uman").*
Forceplate with 4 points with independent force-measuring devices – vertical forces and horizontal forces are recorded and transformed by specials softwares in equilibrium scores.

Equilibrum scores near 100% indicate little sway, while scores near zero indicate that sway is nearing LOS.

Starting from the limits of stability equilibrium scores are calculated both on anterio-posterior direction and in lateral direction.

SENSORY ORGANIZATION TEST (SOT)

The sensory organization test (SOT) assess the patient's balance performance during a sequence of progressively more difficult task conditions. The patient center of gravity projects on the forceplate – he can modify his COG alignment in order to be in the geometrical center of the forceplate using a computer screen.

The patients were standing on INCDMF electronic platform for the balance testing – in 4 conditions:

1) eyes open – rigid support (ODSR – "ochi deschişi – suport rigid");

2) eyes closed – rigid support (OISE – "ochi închişi – suport rigid");

3) eyes open – elastic support (ODSE – "ochi deschişi – suport eleastic");

4) eyes closed – elastic support (OISE – "ochi închişi – suport elastic").

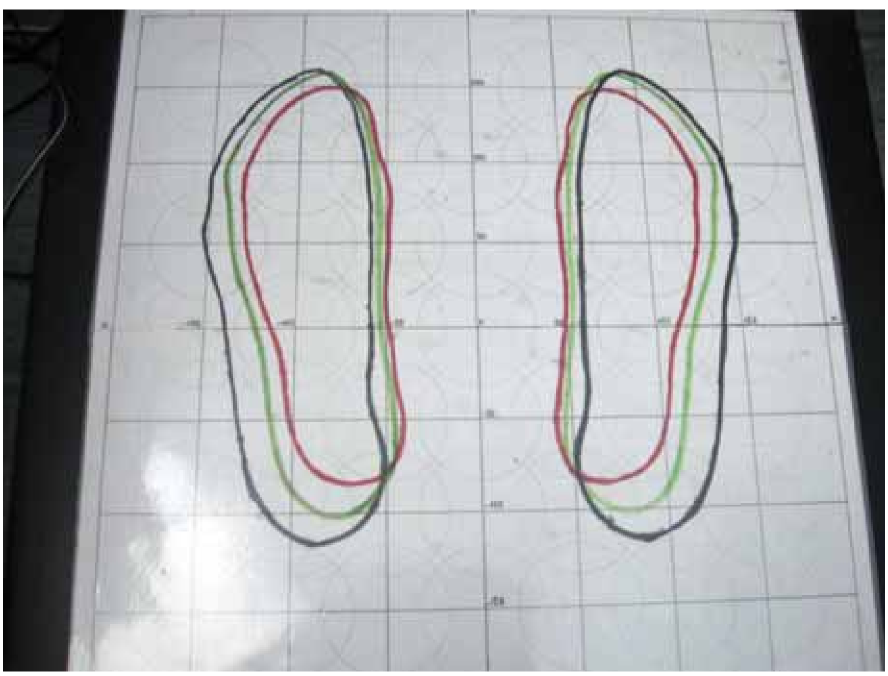

FIGURE 2.

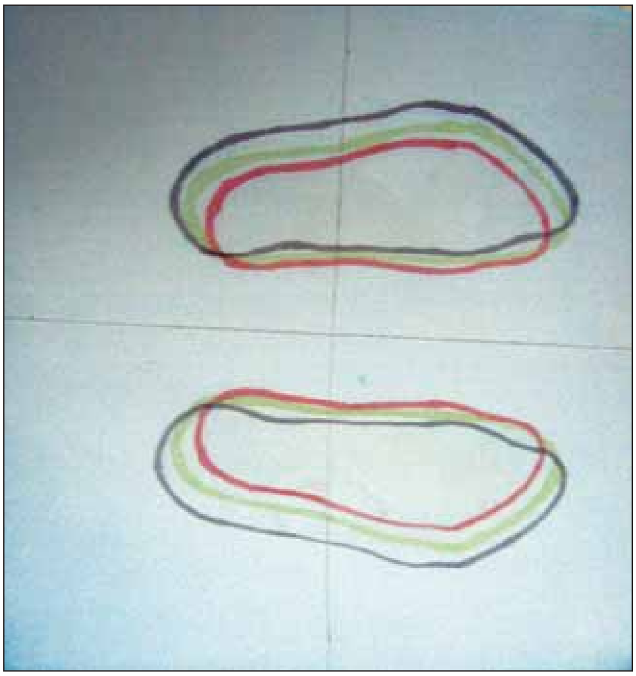

FIGURE 3.

The forceplate is the rigid support (Figure 2). An foam pillow added on the forceplate, of same dimension as the forceplate – is the elastic support (Figure 3).

For each condition we calculated the sensory analysis ratios:

a) **Somatosensory ratio** – compares the condition 2 to the condition 1 equilibrum scores; quantifies the *extent of stability loss when patient closes the eyes;*

The use of somatosensory input is reflected by the ratio between eyes open and eyes closed, on rigid support equilibrium scores. This is equivalent to the classic “Romberg quotient”.

Somatosensory input dominates the control of balance under both eyes open and eyes, hence a normal individ shows a little increase in sway.

If the patient relies on visual rather than somatosensory to maintain balance under fixed surface, there is a significantly increase sway with eye closure.

Low ratio is interpreted as dysfunction of the remainig somatosensory input, which normally dominates the control of balance during stance on a fixed support surface.

b) **Visual ratio** – compares the condition 3 to the condition 1 equilibrum scores; quantifies the *extent of stability loss when the normally dominant somatosensory input is disrupted.*

This ratio extends the concept of Romberg quotient to the visual system. If the patient cannot use the vision in the absence of somatosensory inputs (elastic support), the sway increases.

c) **Vestibular ratio** – compares the condition 4 to the condition 1 equilibrum scores; reflects *reduction in stability when visual and somatosensory inputs are simultaneously disrupted.*

Useful somatosensory inputs are disrupted by elastic support and vision is removed by eye closure. The patients with vestibular dysfunction experiences instability when both somaotsensory and visual inputs are removed.

We compared the patient’s scores with the values from our normal data bank (Table 1,2).

TABLE 1. *Normal values of equilibrum parameters in subjects between 18-60 years old*

Equilibrum parameters	ODSR	OISR	ODSE	OISE
AX (grade)	1	1	2	2.5
AY (grade)	1	1	2	2.5
A_S (grade)	-1	-1	-1.5	-1.75
A_D (grade)	1	1	1.5	1.75
A_A (grade)	1	1	1.5	1.75
A_P (grade)	-1	-1	-1.5	-1.75
X_C (grade)	± 0.5	± 0.5	± 0.5	± 0.5
Y_C (grade)	± 0.5	± 0.5	± 0.5	± 0.5
E_{AP} (%)	≥ 92	≥ 92	≥ 84	≥ 80
E_{SD} (%)	≥ 94	≥ 94	≥ 88	≥ 84
$C_{SOM\ AP}$ (%)		≥ 100		
$C_{SOM\ SD}$ (%)		≥ 100		
$C_{VIS\ AP}$ (%)			≥ 91	
$C_{VIS\ SD}$ (%)			≥ 94	
$C_{VEST\ AP}$ (%)				≥ 87
$C_{VEST\ SD}$ (%)				≥ 89

TABLE 2. *Normal values of equilibrum parameters in healthy subjects o over 60 years old*

Equilibrum parameters	ODSR	OISR	ODSE	OISE
AX (grade)	2	2	4	5
AY (grade)	2	2	4	5
A_S (grade)	-2	-2	-3	-3.5
A_D (grade)	2	2	3	3.5
A_A (grade)	2	2	3	3.5
A_P (grade)	-2	-2	-3	-3.5
X_C (grade)	± 1	± 1	± 1	± 1
Y_C (grade)	± 1	± 1	± 1	± 1
E_{AP} (%)	≥ 84	≥ 84	≥ 68	≥ 60
E_{SD} (%)	≥ 88	≥ 88	≥ 75	≥ 69
$C_{SOM\ AP}$ (%)		≥ 100		
$C_{SOM\ SD}$ (%)		≥ 100		
$C_{VIS\ AP}$ (%)			≥ 81	
$C_{VIS\ SD}$ (%)			≥ 85	
$C_{VEST\ AP}$ (%)				≥ 71
$C_{VEST\ SD}$ (%)				≥ 78

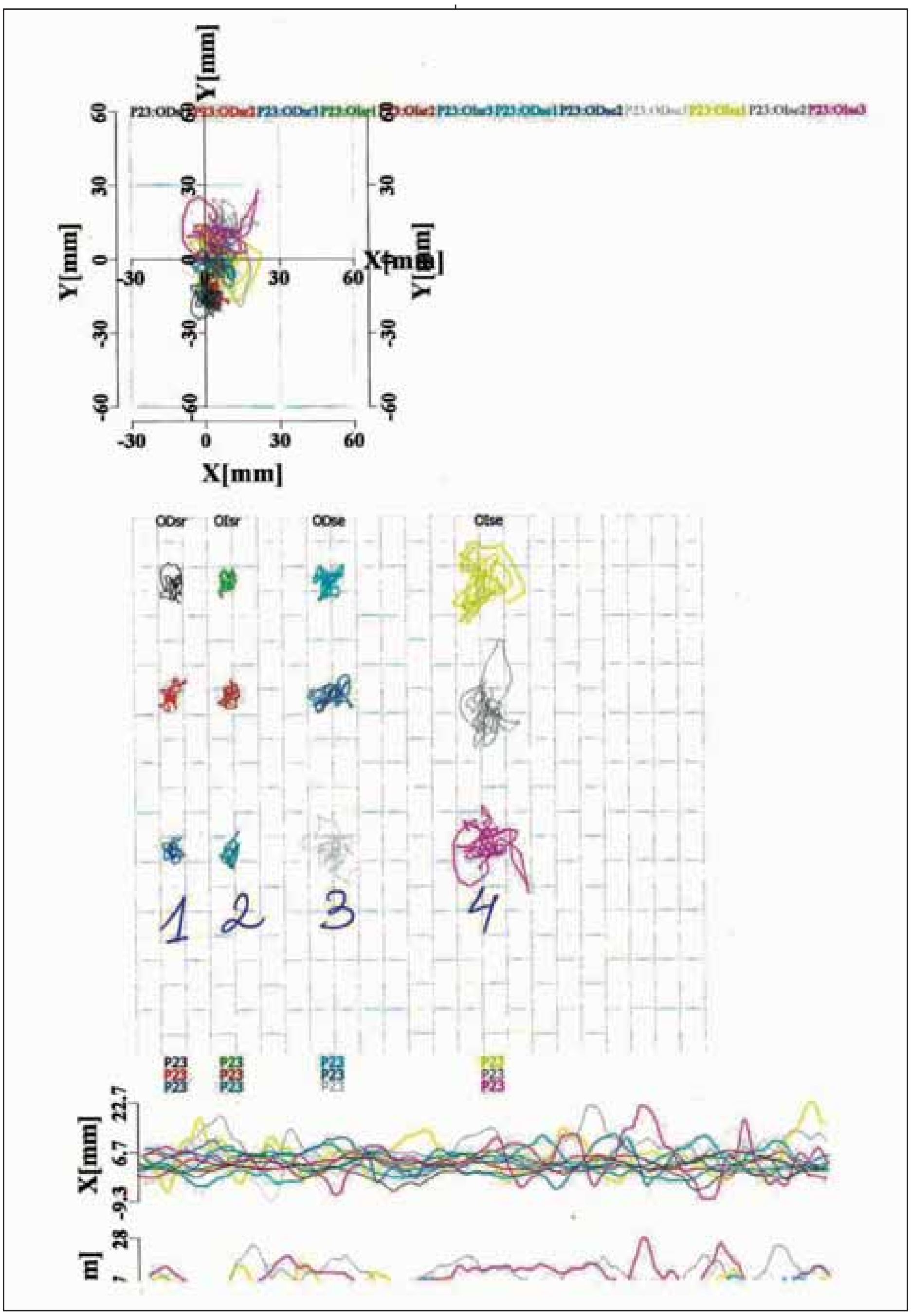

FIGURE 4. *Posturographic examination*
The patient center of gravity projects on the forceplate – he can modify his COG alignment in order to be in the geometrical center of the forceplate using a computer screen
1) eyes open – rigid support; (ODSR – "ochi deschişi – suport rigid") – in the first condition patient is on the forceplate (rigid) with eyes open. We perform 3 tests, each of 20 seconds. All 3 sensory inputs (visual, proprioceptive, vestibular) participate to the balance. The body sway is recorded in the first column.
2) eyes closed – rigid support; (OISE – "ochi închişi -suport rigid") – in the second condition the patient remains on the forceplate (rigid) but with the eyes closed. We perform 3 tests, each of 20 seconds. Proprioceptive and vestibular inputs participate to the balance. Visual inputs are eliminated by closing the eyes. The body sway is recorded in the second column.
3) eyes open – elastic support; (ODSE – "ochi deschişi – suport rigid') – in the third condition the patient is standing on an elastic support (foam pillow) putted on the forceplate, with eyes open. . We perform 3 tests, each of 20 seconds.Visual and vestibular inputs participate to the balance. Proprioceptive inputs are eliminated by the elastic support. The body sway is recorded in the third column.
4) eyes closed – elastic support (OISE – "ochi deschişi-suport elastic") – in the fourth condition the patient is standing on an elastic support (foam pillow) putted on the forceplate, with eyes closed. We perform 3 tests, each of 20 seconds. Vestibular inputs only participate to the balance. Proprioceptive inputs are eliminated by the elastic support and visual inputs are eliminated by closing the eyes. The body sway is recorded in the fourth column.

Cond	Durata (s)	AX (mm)	AY (mm)	Esd (%)	Eap (%)	Rsd (-)	Rap (-)	As (mm)	Ad (mm)	Aa (mm)	Ap (mm)
ODsr1	20.0	9.2	16.3	96.6	92.2	0.0	0.0	-6.1	3.1	0.0	-24.6
ODsr2	20.0	10.8	13.1	96.0	93.8	0.0	0.0	-1.4	9.4	0.0	-19.0
ODsr3	20.0	8.4	11.0	96.9	94.8	0.0	0.0	-1.4	6.9	0.0	-20.8
normal		16.8	16.8	93.7	92.0	0.0	0.0	-16.8	16.8	16.8	-16.8
OIsr1	20.1	6.9	11.6	97.4	94.4	1.0	1.0	0.0	6.9	0.0	-21.0
OIsr2	20.0	8.8	11.1	96.7	94.7	1.0	1.0	-2.2	6.5	0.0	-21.9
OIsr3	20.0	7.4	15.3	97.2	92.7	1.0	1.0	-4.2	3.2	0.0	-23.6
normal		16.8	16.8	93.7	92.0	1.0	1.0	-16.8	16.8	16.8	-16.8
ODse1	20.1	12.0	14.4	95.5	93.1	0.0	0.0	0.0	12.0	7.3	-7.1
ODse2	20.0	17.9	15.3	93.3	92.7	0.0	0.0	-5.6	12.3	4.1	-11.2
ODse3	20.0	23.7	27.7	91.2	86.8	0.0	0.0	-9.3	14.4	13.6	-14.1
normal		33.6	33.6	87.5	84.0	0.0	0.0	-25.2	25.2	25.2	-25.2
OIse1	20.0	28.8	33.2	89.2	84.2	0.9	0.9	-6.2	22.7	14.5	-18.7
OIse2	20.2	23.8	43.9	91.1	79.0	1.0	0.9	-2.3	21.5	24.4	-19.5
OIse3	20.1	30.4	35.1	88.7	83.3	1.0	1.0	-9.0	21.4	28.0	-7.1
normal		42.0	42.0	84.3	80.0	1.0	1.0	-29.4	29.4	29.4	-29.4

Cond	Es (%)	Ed (%)	Ea (%)	Ep (%)	Rs (-)	Rd (-)	Ra (-)	Rp (-)	Xc (mm)	Yc (mm)
ODsr1	95.5	97.6	85.5	91.3	0.0	0.0	0.0	0.0	-1.5	-16.4
ODsr2	96.4	95.5	89.0	93.0	0.0	0.0	0.0	0.0	4.0	-12.5
ODsr3	97.0	96.7	86.1	94.4	0.0	0.0	0.0	0.0	2.7	-15.3
normal	87.5	87.5	84.6	83.3	0.0	0.0	0.0	0.0	-8.4/8.4	-8.4/8.4
OIsr1	97.5	97.3	85.4	94.9	1.0	1.0	1.0	1.0	3.5	-15.2
OIsr2	96.2	97.2	85.4	94.0	1.0	1.0	1.0	1.0	2.2	-16.4
OIsr3	96.9	97.6	86.6	91.1	1.0	1.0	1.0	1.0	-0.5	-15.9
normal	87.5	87.5	84.6	83.3	1.0	1.0	1.0	1.0	-8.4/8.4	-8.4/8.4
ODse1	95.8	95.3	93.1	93.1	0.0	0.0	0.0	0.0	6.0	0.1
ODse2	92.7	94.0	93.7	91.6	0.0	0.0	0.0	0.0	3.4	-3.6
ODse3	90.6	91.7	87.8	85.7	0.0	0.0	0.0	0.0	2.5	-0.2
normal	81.2	81.2	76.9	75.0	0.0	0.0	0.0	0.0	-8.4/8.4	-8.4/8.4
OIse1	91.6	86.9	84.7	83.5	1.0	0.9	0.9	0.9	8.3	-2.1
OIse2	92.0	90.2	85.2	72.4	1.0	1.0	0.9	0.8	9.6	2.5
OIse3	90.2	87.1	81.6	85.1	1.0	0.9	0.9	1.0	6.2	10.4
normal	78.1	78.1	73.0	70.8	1.0	1.0	0.9	0.9	-8.4/8.4	-8.4/8.4

FIGURE 5. *Equilibrum scores*

Durata (s) = Duration = 20 seconds
Xc = COG (center of gravity) alignment in lateral direction
Yc-COG (center of gravity) alignemt in antero-posterior direction
AX (mm) = maximum amplitude of sway in lateral (left-right) direction
As (mm) = maximum amplitude of sway in left direction
Ad (mm) = maximum amplitude of sway in right direction
AY (mm) = maximum amplitude of sway in antero-posterior direction
Aa (mm) = maximum amplitude of sway in anterior direction
Ap (mm) = maximum amplitude of sway in posterior direction
Esd (%) = equilibrium score in lateral direction (left-right, “stanga-dreapta”) direction
Es (%) = equilibrium score in lateral left direction
Ed (%) = equilibrium score in lateral right direction
Eap (%) = equilibrium score in antero-posterion direction
Ea (%) = equilibrium score in anteror direction
Ep (%) = equilibrium score in posterior direction
Rsd = ratio of parametres in left-right direction
Rs = ratio of parametres in left direction
Rd = ratio of parametres in right direction
Rap = ratio of antero-posterior in antero-posterior direction
Ra = ratio of parametres in anterior direction
Rp= ratio of parametres in left-right direction

UNIVERSITY EMERGENCY HOSPITAL OF BUCHAREST – NEUROLOGY DEPARTMENT. STATIC POSTUROGRAPHY STUDY IN ISCHAEMIC STROKE PATIENTS

The objective of our study was to assess the contribution of these sensory channels in the balance of patients with recent ischemic stroke by using computerized static posturography (CSP).

Methods

We studied 38 patients with vertigo and imbalance who experienced a recent minor ischemic stroke.

First, the patient had to align his center of gravity on the geometrical center of the forceplate, usiong a computer screen to adjust his position.

X_c = COG (center of gravity) alignment in lateral direction

Y_c = COG (center of gravity) alignemt in antero-posterior direction

The patients were standing on INCDMF – CEFIN electronic platform for the balance testing – in 4 conditions:

1) eyes open – rigid support;
2) eyes closed – rigid support;
3) eyes open – elastic support;
4) eyes closed – elastic support. (Figure 2,3)

For each condition we performed 3 testes. Each lasting 20 seconds (Durata (s) = Duration = 20 seconds).

Using software we calculate:

AX (mm) = maximum amplitude of sway in lateral (left-right) direction

As (mm) = maximum amplitude of sway in left direction

Ad (mm)= maximum amplitude of sway in right direction

AY (mm) = maximum amplitude of sway in antero-posterior direction

Aa (mm) = maximum amplitude of sway in anterior direction

Ap (mm) = maximum amplitude of sway in posterior direction

Esd (%) = equilibrium score in lateral direction (left-right, "stânga-dreapta") direction

Es (%) = equilibrium score in lateral left direction

Ed (%) = equilibrium score in lateral right direction

Eap (%) = equilibrium score in antero-posterion direction

Ea (%) = equilibrium score in anteror direction

Ep (%) = equilibrium score in posterior direction

Rsd = ratio of parametres in left-right direction

Rs = ratio of parametres in left direction

Rd = ratio of parametres in right direction

Rap = ratio of antero-posterior in antero-posterior direction

Ra = ratio of parametres in anterior direction

Rp = ratio of parametres in left-right direction

LOS = LIMITS OF STABILITY = ellipse with antero-posterior diameter of $12,5^0$ and lateral diameter of 16^0. (5,6)

$$E_{AP} = \frac{LOS_{AP}\text{-}AY}{LOS_{AP}} \times 100 = \frac{12,5 - AY}{12,5} \times 100$$

$$E_{SD} = \frac{LOS_{SD}\text{-}AY}{LOSD} \times 100 = \frac{16 - AY}{16} \times 100$$

For each condition we calculated the **sensory analysis ratios** (both in antero-posterior and lateral direction):

– **Somatosensory ratio** – compares the condition 2 to the condition 1 equilibrum scores; quantifies the *extent of stability loss when patient closes the eyes;*

$$C_{SOM\ AP} = E_{AP\ (OISR)} / E_{AP\ (ODSR)} \text{ X } 100$$

$$C_{SOM\ SD} = E_{SD\ (OISR)} / E_{SD\ (ODSR)} \text{ X } 100$$

– Visual ratio – compares the condition 3 to the condition 1 equilibrum scores; quantifies the *extent of stability loss when the normally dominant somatosensory input is disruted.*

$$C_{VIS\ AP} = E_{AP\ (ODSE)} / E_{AP\ (ODSr)} \text{ X } 100$$

$$C_{SOM\ SD} = E_{SD\ (ODSe)} / E_{SD\ (ODSR)} \text{ X } 100$$

– Vestibular ratio – compares the condition 4 to the condition 1 equilibrum scores; reflects *reduction in stability when visual and somatosensory inputs are simultaneously disrupted.*

$$C_{Vest\ AP} = E_{AP\ (OISE)} / E_{AP\ (ODSR)} \text{ X } 100$$

$$C_{SOM\ SD} = E_{SD\ (Oise)} / E_{SD\ (ODSR)} \text{ X } 100$$

We compared them with the values from our normal data bank of age-matched subjects. (Table 1, 2)

Results

In our group we studied 38 patients (20 men and 18 women). The age range was between 37-80 years (mean age 62,42).

All patients experienced a recent minor ischemic stroke and complain about imbalance.

The vascular territory involved was carotidian in 11 patients and vertebro-basilar in 27 patients.

We found more than 5% deviation from normal range of the sensory scores as follows:

- 29 patients – multisensory impairment (with at least 2 sensory inputs altered):
- 2 sensory inputs altered:
  11 – with vestibular and somatosensory impairment,
  7 – with visual and somatosensory impairment,
- 3 sensory inputs altered:
  11 – with visual, vestibulary and somatosensorial impairment;
  9 – isolated vestibular impairment.

CONCLUSIONS

Posturography evaluates the stability of the body and also equilibrum scores. This is a method of measuring the participation of proprioceptive, visual and vestibular input in keeping the balance.

Computerized dynamic posturography can also be used in diagnostic of presbyatasis and in the treatment of age related balance disorder, in vestibular rehabilitation (20).

Computerized static posturography (CSP) is useful to assess the type of sensory (visual, proprioceptive, vestibular) impairment cause inbalance in stroke patients. Vertigo and imbalance in ischemic stroke patients is usually caused by is a **multisensory impairment pattern**. Therefore, complex *balance training exercises are needed in central compensation after ischemic stroke. (19)*

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