ORIGINAL ARTICLE

Static Posturography With Dynamic Tests. Usefulness of Biomechanical Parameters in Assessing Vestibular Patients

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Abstract

Introduction and objective: Posturography allows us in evaluating postural control. This study showed the posturographic parameters that were useful for assessing the functional ability to maintain balance in our sample of vestibular patients.

Material and methods: Of a total of 89 patients, 59 were healthy subjects and 30 had a peripheral vestibular disorder. The subjects were studied using the posturographic NedSVE/IBV system, combining static (Romberg) and dynamic (stability limits and rhythmic weight shifts) tests. We then compared the measurements found in the groups.

Results: Normal subjects showed significantly lower oscillations than our patients in all of the posturographic parameters studied (except the displacement angle). In testing the limits of stability, although normal subjects achieved maximum displacements greater than the subjects with the disorder, the differences found were not significant. In rhythmic weight shift tests, normal subjects showed more favourable results than did the vestibular patients, with significant differences in 3 of the 4 parameters studied: (1) anteroposterior ability, (2) mediolateral ability, and (3) anteroposterior control and efficiency.

Conclusion: Rhythmic weight shift tests and the static posturography test parameters used were useful in discriminating among the normal and pathological subjects in this study.

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KEYWORDS
Balance; Equilibrium; Postural control; Posturography; Vestibular disorders

PALABRAS CLAVE
Estabilidad; Equilibrio; Control postural; Posturografía;

Posturografía estática con pruebas dinámicas. Utilidad de los parámetros biomecánicos en la valoración del paciente vestibular

Resumen

Introducción y objetivos: La posturografía permite evaluar el control postural de un sujeto. En este estudio se presentan aquellos parámetros biomecánicos del sistema de posturografía...
Trastornos vestibulares

Introduction

The ability to control posture spontaneously or in response to external alterations is known as postural control (PC). It consists of maintaining the position of the body, specifically the centre of gravity, within certain stability limits (SL). This process begins in the vestibular, visual, and somatosensory receptors, whose afferents are processed and integrated by various structures of the central nervous system and lead to mechanical actions of the musculoskeletal system. The instrumental study of PC as a means to quantify and objectively instability has led to the development of posturography techniques which analyse standing balance in situations of increasing complexity and report on the functional status of studied subjects. They are based on the use of dynamometric platforms which register the movements of the centre of pressures of a subject.1-5

The "gold standard" technique for the study of PC is computerised dynamic posturography (CDP) or EquiTest (NeuroCom® Inc., Clackamas, OR, USA).6 The American Academy of Otolaryngology and Head and Neck Surgery recognises CDP as an appropriate test for the evaluation and treatment of patients with vestibular lesions.7 The American Academy of Neurology8 considers it as a useful system to analyse the ability to maintain PC in both healthy and pathological individuals, while the American Medical Association regards it as a method to objectify deficits and disabilities.

Other posturography models have been gradually developed since the onset of CDP. These provide information which, albeit not equivalent, may be equally useful in the assessment of unstable patients. One such system is the NedSVE®/IBV developed by the Institute of Biomechanics of Valencia (IBV).

The NedSVE® system created by the IBV is an application for the functional evaluation of balance disorders which combines static posturography tests with dynamic exercises. The assessment of each test is based on the calculation of certain biomechanical parameters which reflect the displacement of the pressure centre of the subject.

This work aims to determine which of the parameters (see "Material and Methods" section) used by the posturography system are relevant in the functional evaluation of unstable patients. To do this, we compared the results of static posturography, SL tests, and rhythmic weight shifts (RWS) tests between healthy subjects and subjects suffering vestibular disorders of peripheral origin.

Material and Methods

The sample consisted of 59 participants without known disease, which we considered as normal subjects, and 30 with vestibular disease, which we considered as pathological subjects.

Normal Subjects

Normal subjects underwent a detailed medical history in order to rule out episodes of vertigo, imbalance or instability. We excluded all those who presented neurological, ophthalmological, psychiatric or musculoskeletal system diseases. In addition, we did not include patients who were following treatment with drugs affecting the central nervous system (antidepressants, neuroleptics, benzodiazepines, anticonvulsants, vestibular sedatives, etc.).

Pathological Subjects

The pathological group consisted of previously diagnosed patients monitored at the Otolaryngology Service of Hospital Dr. Peset and Hospital de la Ribera in Valencia, who had a clinical history of balance disorders due to peripheral vestibular disease. We excluded subjects with neurological, ophthalmological, psychiatric or musculoskeletal system diseases which could be the cause of imbalance or which impeded understanding or conducting the tests. Moreover, we did not include patients following treatment with drugs which acted on the central nervous system (antidepressants,
neuroleptics, benzodiazepines, anticonvulsants, vestibular sedatives, etc.).

Table 1 describes the clinical entities presented by studied patients. All subjects in the sample reported vertigo, dizziness or instability within the 6 weeks prior to the completion of posturography. The monitoring period for diagnosis ranged from 1 to 5 years.

Patients underwent a detailed history, a complete otoneurological examination and an audio-vestibular study. The otoneurological examination included an analysis of spontaneous nystagmus (with and without fixed vision), positional nystagmus, oculocephalic manoeuvre, and cephalic shaking nystagmus. The audio-vestibular study was based on: (1) liminal tone audiometry along with other audiological tests (depending on the liminal tonal audiometry) with a clinical audiometer (Interacoustics® A/S AC 40 with TDH 39 earphones and a Radioear® B71 bone conductor), and (2) a study of the extrinsic ocular motility (saccades, tracking and optokinetic nystagmus) along with caloric tests (CT) irrigating the external auditory canal with water (150 µl at 30–44 °C in 30 s), and nystagmus recorded by videonystagmography (Ulmer VNG, v.1.4, SYNAPSIS®, Marseille, France). The parameters used were canicular paresis and directional preponderance, according to the Jongkees formula. Values below 20% and 28%, respectively, were considered normal.

All patients underwent a consultation at the Neurology Service, in order to discard any disorders with a central origin.

This exploration was conducted in support of the diagnosis of vestibulopathy. Its results were compared with those found through the instrumental exploration, which are described below.

All subjects in the sample underwent an instrumental study using the NedSVE®/IBV system and following the protocol and methodology recommended by the IBV, including static posturography with dynamic tests.9

Instrumental Study

Static Posturography Tests
PC was measured under various conditions: Romberg with open eyes (ROE), Romberg with closed eyes (RCE), Romberg on a foam mattress with open eyes (RFO), Romberg on a foam mattress with closed eyes (RFC). Tests were conducted by increasing difficulty: (1) ROE, (2) RCE, (3) RFO and, finally, (4) RFC.

The following biomechanical parameters were recorded during each of these tests: (1) displacement angle (°): this is the orientation of the displacement vector expressed in degrees. The displacement vector extends from the initial starting point of the subject to the final position; (2) sweep area (mm²): this is the approximate area in which subject balancing takes place. In order to obtain this calculation, the software application determines an ellipse encompassing a cloud of points representing the path of the subject during the duration of the test; (3) mean speed (m/s): this is the total distance travelled by the pressure centre during the test divided by the time elapsed; (4) maximum mediolateral and anteroposterior displacements (mm): these represent the farthest point reached by the centre of pressures in the mediolateral and anteroposterior axes during the registration time; and (5) maximum mediolateral and anteroposterior forces (N): these are the maximum forces registered during the exercise in a mediolateral and anteroposterior direction, expressed in Newtons.

Control and Ability Assessment Tests
This included the assessment of SL and analysis of the RWS. In the SL test, subjects had to seek the position of greatest stability whilst standing with arms relaxed and parallel to the body and feet positioned so that the heels were touching and the toes were diverging at an angle of 30°. Next, whilst looking at a computer monitor placed in front and at eye level and without altering their base of support, subjects had to move a cursor which reflected the position of their centre of gravity towards 8 targets located in their theoretical SL, at intervals of 45°. The subjects were given 8 s to move their centre of gravity to each target and had to remain there as long as they could. The distance at which each of them appeared depended on the age and height of the subject. The biomechanical parameter calculated for each SL (front, front-right, right, rear-right, rear, rear-left, left and front left) was the maximum displacement (%), which was represented by the percentage obtained with respect to the normality pattern (segmented by gender, age and height) of greatest displacement achieved in each direction.

In the RWS test, subjects had to look at a monitor placed in front and at eye level and follow the rhythmic motion of a moving target with the projection of their centre of gravity. The study consisted of 2 tests; one in which the target moved horizontally and another in which it moved vertically at 3 different speeds: slow, medium, and fast. In order to perform this exercise, it was necessary to have previously determined the SL of the subject. The following biomechanical parameters were calculated in this test: (a) ability (%): this estimated how closely the subjects followed the motion of the target with the movement of their centre of gravity; and (b) control and efficacy (%): this estimated how closely the subjects followed the motion of the target with the perpendicular movement of their centre of gravity.

Statistical Analysis
The final database was elaborated using the software package SPSS® v.17. The evaluation of results consisted of a descriptive analysis and a comparative analysis.
Figure 1  Gender distribution of normal and pathological subjects.

The descriptive analysis of variables took into account whether they presented a parametric distribution or not (Kolmogorov–Smirnov test). If they were parametric, then the arithmetic mean and standard deviation were used as measures of central tendency and dispersion, respectively.

Sample differences were considered statistically significant when they reached values of P<.05.

Results

The total sample consisted of 43 males and 46 females. Among the normal subjects, 29 were male and 30 were female. Among the pathological subjects, 14 were male and 16 were female (Fig. 1). The general characteristics of both groups are reflected in Table 2. Sample subjects reported suffering symptoms of vertigo, dizziness or unsteadiness 22.36±13.66 days prior to posturography.

All subjects underwent the instrumental study. We observed that both normal and pathological patients had less balancing in the ROE test, somewhat greater in the RCE test, greater still in the RFO test, and the greatest oscillations were recorded in the RFC test. This oscillation increase was reflected in all parameters of the static posturography, with the exception of the displacement angle (Table 3).

Normal subjects presented less oscillations than all pathological subjects in the different biomechanical parameters studied (except for the displacement angle), with statistically significant differences (Table 4).

In the SL test, normal subjects achieved greater maximum displacements than pathological subjects (except for the rear SL), although the differences found were not statistically significant. The descriptive and comparative results of this test are shown in Tables 5 and 6, respectively.

Normal subjects presented more favourable results than pathological subjects in the rhythmic weight shifts test (Table 7). The differences between both groups were statistically significant in 3 of the 4 parameters studied: (1) anteroposterior ability, (2) mediolateral ability, and (3) anteroposterior control and efficacy (Table 8).

Discussion

In some patients, posturography can detect the negative influence exerted by a vestibular alteration on postural stability. It does not replace the classic tests which evaluate

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Mean and Standard Deviation of the General Characteristics of the Sample.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Age, years</td>
<td>49.15 ± 18.15</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>74.00 ± 16.13</td>
</tr>
<tr>
<td>Size, cm</td>
<td>167 ± 9.26</td>
</tr>
<tr>
<td>BMI</td>
<td>26.42 ± 4.70</td>
</tr>
</tbody>
</table>

BMI: body mass index.
the vestibulo-ocular reflex, but instead provides complementary information, enabling a better understanding of the functional status of patients with instability.

In his posturography work, Norrè studied 3 classical groups of vestibular conditions: (1) patients with benign paroxysmal positional vertigo (BPPV); (2) patients with spontaneous vertigo crises, including patients with Menière’s disease or those suffering recurrent vertigo without auditory involvement classified as recurrent vestibulopathy; and (3) patients with sudden unilateral hearing loss, of a vestibular neuritis type.\textsuperscript{10,11} Coinciding with Norrè, our study included patients with vestibular disorders, although with a more heterogeneous distribution of conditions. In turn, we could not include patients with BPPV in the study since such patients were not available during the data collection period.

This work has included both patients with acute vertigo and those with symptoms of dizziness or unsteadiness. Since we included cases with such heterogeneous diagnoses and symptoms, we could not determine the time elapsed since the last crisis until the time of the study, because not all patients followed the same pattern. It would also have been desirable to establish the compensation status of patients, but we did not conduct the examinations required for this purpose. In any case, all subjects in the sample reported vertigo, dizziness or instability within 6 weeks prior to the completion of the posturography assessment.

The static posturography measurements obtained in our study reflected a progressive and logical evolution in the degree of difficulty of the tests. The simplest test was the ROE, followed by the RCE, the RFO, and finally the RFC, thus corroborating the reports of Norrè.\textsuperscript{10}

### Table 4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ROE</th>
<th>RCE</th>
<th>RFO</th>
<th>RFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement angle, $^a$</td>
<td>.003</td>
<td>.302</td>
<td>.815</td>
<td>.426</td>
</tr>
<tr>
<td>Sweep area, mm$^2$</td>
<td>.004</td>
<td>.001</td>
<td>.001</td>
<td>.002</td>
</tr>
<tr>
<td>Mean velocity, m/s</td>
<td>.001</td>
<td>.002</td>
<td>.001</td>
<td>.003</td>
</tr>
<tr>
<td>Mediolateral displacement, mm</td>
<td>.003</td>
<td>.002</td>
<td>.001</td>
<td>.002</td>
</tr>
<tr>
<td>Anteroposterior displacement, mm</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.005</td>
</tr>
<tr>
<td>Maximum mediolateral force, N</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
</tr>
<tr>
<td>Maximum anteroposterior force, N</td>
<td>.007</td>
<td>.006</td>
<td>.001</td>
<td>.040</td>
</tr>
</tbody>
</table>

\textsuperscript{a} P < .05.

### Table 5

Mean and Standard Deviation of the Maximum Displacements of Normal and Pathological Subjects.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Pathological</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Front</td>
<td>108.66</td>
<td>5.97</td>
</tr>
<tr>
<td>Front right</td>
<td>102.21</td>
<td>8.85</td>
</tr>
<tr>
<td>Right</td>
<td>104.69</td>
<td>10.01</td>
</tr>
<tr>
<td>Rear left</td>
<td>109.02</td>
<td>9.12</td>
</tr>
<tr>
<td>Rear</td>
<td>102.45</td>
<td>12.41</td>
</tr>
<tr>
<td>Rear left</td>
<td>104.16</td>
<td>10.48</td>
</tr>
<tr>
<td>Left</td>
<td>102.88</td>
<td>10.36</td>
</tr>
<tr>
<td>Front left</td>
<td>102.38</td>
<td>7.26</td>
</tr>
</tbody>
</table>

SD: standard deviation.

### Table 6

Mean and Standard Deviation of the Ability and Control and Efficacy Results in the Rhythmic Weight Shifts Test Between Normal and Pathological Subjects.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Pathological</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Mediolateral ability</td>
<td>99.07</td>
<td>3.46</td>
</tr>
<tr>
<td>Mediolateral control and efficacy</td>
<td>97.33</td>
<td>8.34</td>
</tr>
<tr>
<td>Anteroposterior ability</td>
<td>99.37</td>
<td>2.36</td>
</tr>
<tr>
<td>Anteroposterior control and efficacy</td>
<td>97.78</td>
<td>6.93</td>
</tr>
</tbody>
</table>

SD: standard deviation.

### Table 7

Statistical Significance ($P$) of the Comparison Between Parameters of the Rhythmic Weight Shifts Test Between Normal and Pathological Subjects.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Pathological</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediolateral ability</td>
<td></td>
<td></td>
<td>.027$^a$</td>
</tr>
<tr>
<td>Mediolateral control and efficacy</td>
<td></td>
<td></td>
<td>.397</td>
</tr>
<tr>
<td>Anteroposterior ability</td>
<td></td>
<td></td>
<td>.035$^a$</td>
</tr>
<tr>
<td>Anteroposterior control and efficacy</td>
<td></td>
<td></td>
<td>.031$^a$</td>
</tr>
</tbody>
</table>

$^a$ $P < .05$. 

### Table 8
With the exception of the displacement angle, all biomechanical parameters of the static posturography were capable of discriminating between the normal and pathological subjects in our sample. The reason for this exception is that the displacement angle does not measure the level of oscillation, but only the direction of displacement of the centre of pressures. Unlike the observations by Ortuño-Cortés et al.,12 the mean speed showed a similar pattern to the other parameters, as it correctly reported the oscillations of the examined subject.10,13,14

Pressure centre studies using dynamometric platforms have mostly focused on static posturography tests or the sensory organisation test in CDP. However, very few works have investigated the SL and their importance in the functional assessment of unstable patients. The same applies to rhythmic weight shifts studies, as we will see later.

The SL can be defined as the maximum angle, measured from the vertical, which an individual can bend without changing his base of support.15 The results can be affected by different factors: they are worse in patients with total hip prostheses,16 Parkinson’s disease patients in the off stage17 and also when subjects carry a load near the top of the body.18 By contrast, an increase in quadriceps strength,19 a balance training programme in patients with Parkinson’s disease20 and intensive practice of Tai Chi are related to an improvement in these values.21

Normal and pathological subjects studied obtained similar scores in the maximum displacements of the SL, so these tests do not seem to be relevant for the functional assessment of patients in our sample. This finding is consistent with that reported by Ortuño-Cortés et al.22

Like the SL, the RWS test reports on the capacity of subjects to carry out movements in a safe manner. The descriptive study of our sample indicated that the group of pathological patients obtained worse scores than that of normal subjects, and that these differences were statistically significant in 3 of the 4 parameters studied: (1) anteroposterior ability, (2) mediolateral ability, and (3) anteroposterior control and efficiency. These results differ from those observed by Ortuño-Cortés et al.,21 since this author found no differences between the patient group and the control group, although the scores of normal participants were better in the descriptive study.

In light of the findings, vestibular disorders may be able to significantly alter the voluntary control of rhythmic movement whilst standing. However, since our results were obtained with a heterogeneous and small sample compared with the control group, no conclusions can be extrapolated to vestibular condition in general. Further studies with greater casuistry would be required in order to determine the usefulness of the RWS test to discriminate vestibular patients from healthy subjects.

Conclusions
- The exception of the displacement angle, all biomechanical parameters of static posturography were able to discriminate between normal and pathological subjects in our sample.
- The SL test had little interest for functional assessment of patients in our sample.
- The RWS test proved useful to discriminate between normal and pathological subjects in our sample. Therefore, vestibular disorders may be able to significantly alter the voluntary control of rhythmic movement whilst standing.

Conflict of Interests

The authors have no conflict of interests to declare.

Acknowledgement

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