Eur Arch Otorhinolaryngol (2011) 268:1569–1574
DOI 10.1007/s00405-011-1532-z

OTOLOGY

What is the most effective vestibular rehabilitation technique in patients with unilateral peripheral vestibular disorders?

Marcos Rossi-Izquierdo · Sofia Santos-Pérez · Andrés Soto-Varela

Received: 14 September 2010 / Accepted: 7 February 2011 / Published online: 22 February 2011

Abstract Vestibular rehabilitation has been found to be effective and safe in patients with instability. There is insufficient evidence, however, for distinguishing between the efficacies of different rehabilitation techniques. The objective of this study is to verify whether there are differences between two instrumental vestibular rehabilitation techniques, computerised dynamic posturography (CDP) and optokinetic stimulation (OKN), in order to establish the optimal strategy for each patient. We conducted a prospective, comparative study of the two techniques (CDP and OKN) in patients with instability due to chronic unilateral peripheral vestibular disorder. We randomly included 12 patients in each group, performing the evaluation with the Dizziness Handicap Inventory and the CDP with the sensorial organisation test (SOT), rhythmic weight shift and limits of stability (LOS). We found a statistically significant improvement in both groups in average balance score according to the SOT. In the OKN group, however, improvement was greater in visual preference. The CDP group showed greater benefits in the visual and vestibular input and LOS. Patients with poor vestibular and visual input or with reduced LOS will benefit more from an exercise protocol with CDP. Patients with poor visual preference, however, are ideal candidates for rehabilitation with OKN.

Keywords Computerised dynamic posturography · Optokinetic stimulation · Vestibular rehabilitation · Instability · Unilateral peripheral vestibular disorders

Introduction

Vestibular rehabilitation can be defined as the set of exercises designed to favour central nervous system plasticity by means of adaptation or the generation of substitute mechanisms in patients with balance disorders, in order to improve their global stability and to help them resume daily activities.

It is indicated in patients with instability of different origins [1]: unilateral [2] or bilateral peripheral lesion [3], presbivertigo [4] and central aetiology [5, 6].

There are systematic reviews [2] that show that it is effective and safe in adult patients with instability due to chronic unilateral peripheral disorders; moreover, these benefits persist over time. However, there is insufficient evidence to distinguish between the efficacies of different rehabilitation techniques.

If vestibular rehabilitation is effective in these patients, and none of the techniques has been shown to be better than the other, we need to ask ourselves whether all types of rehabilitation are effective for all patients [7].

The objective of this study is to verify the efficacy of two different instrumental vestibular rehabilitation techniques, computerised dynamic posturography (CDP) and optokinetic stimulation (OKN), in patients with instability due to chronic unilateral peripheral disorders and to identify any

M. Rossi-Izquierdo (✉)
Department of Otolaryngology,
University Hospital Lucus Augusti,
San Cibrao s/n, 27003 Lugo, Spain
e-mail: Marcos_Rossi@hotmail.com

S. Santos-Pérez · A. Soto-Varela
Department of Otolaryngology,
University Hospital of Santiago de Compostela,
Santiago de Compostela, Spain

possible differences between them in order to establish the optimal strategy for each patient.

Materials and methods

We conducted a prospective vestibular rehabilitation study from January 2008 to April 2010 in patients with instability due to chronic unilateral peripheral disorder (not spontaneously resolved within a month of onset). The study was conducted in the Department of Otolaryngology of a tertiary university hospital.

We used balanced block randomisation to include 12 patients in each treatment group (CDP and OKN). To ensure correct diagnosis, all the patients underwent anamnesis, otoneurological examination, liminal tone audiometry, caloric testing by videonystagmography and the sensorial organisation test (SOT) by CDP. The study was supplemented whenever necessary with imaging in order to rule out inner ear and pontocerebellar lesions and post-traumatic conditions.

As an inclusion criterion, patients were required to present vestibular hypofunction in the caloric tests, defined as at least 25% labyrinthic preponderance according to the Jongkees formulas [8]. Maximum slow-phase angular velocity was measured in the 30 s of culmination of response. Caloric testing was performed with 50 cc of water at 44°C and 30°C, with 40 s of stimulation, following the sequence described by Bartual [9], with the tests performed 5 min apart.

The exclusion criteria for this study were locomotor disorders preventing standing, previous instrumental vestibular rehabilitation or the lack of a complete evaluation. During the study, none of the patients was treated with vestibular sedatives or other drugs to mitigate their instability symptoms.

The sample in the OKN treatment group comprises 9 women and 3 men with a mean age of 48.83 years (range 28–75). Duration of symptoms was an average of 18.58 months (range 2–120 months).

The sample in the CDP group comprised 7 women and 5 men with a mean age of 54.5 years (range 30–82). Duration of symptoms was an average of 16.33 months (range 2–84 months).

The origin of the balance disorders in the two groups is summarised in Table 1. There were no statistically significant differences between the groups regarding age and duration of symptoms (Mann–Whitney test) or gender (Chi-square test). All the patients consented to participate in the study according to the Declaration of Helsinki.

The patients were assessed on the day before rehabilitation started and 3 weeks after completing the treatment.

This assessment consisted of:

- Dizziness Handicap Inventory (DHI) score (validated Spanish version [10]). It is a questionnaire related to balance-derived handicaps used to quantify the impact of balance disorders on everyday activities. It can also be used for measuring how symptoms affect quality of life. It consists of 25 items divided into three groups (functional, emotional and physical), with three possible answers: “yes” (four points), “sometimes” (two points) and “no” (no points). The maximum score (representing the greatest handicap) is therefore 100.
- CDP [11]. We used the Neurocom® Smart Balance Master. The platform surface contacts with four symmetrical transducers that measure vertical forces, and a central transducer that measures the horizontal force on the antero-posterior axis parallel to the floor. It is surrounded by a mobile, display screen. This screen, or visual environment, can move simultaneously with the platform, both of which are computer controlled. The SOT, the rhythmic weight shift (RWS), and the limits of stability (LOS) tests were performed with this platform. The SOT analyses the relative involvement of somatosensory, visual and vestibular receptors in the patient’s overall

Table 1 Aetiology of instability in the vestibular rehabilitation groups

CDP group		OKN group	
Diagnosis	*n*	Diagnosis	*n*
Labyrinthic infarction	3	Vestibular neuronitis	5
Labyrinthic damage from intratympanic gentamicin treatment in patient with unilateral Meniere’s disease	3	Labyrinthic damage from intratympanic gentamicin treatment in patient with unilateral Meniere’s disease	4
Post-surgical unilateral vestibular dysfunction	2	Post-traumatic labyrinthic concussion	1
Labyrinthic haemorrhage	1	Complete Ramsay Hunt syndrome	1
Surgical labyrinthectomy in patients with unilateral Meniere’s disease	1	Post-surgical unilateral vestibular hypofunction	1
Post-traumatic labyrinthic concussion	1		
Vestibular neuronitis	1		

n number of cases

stability, showing which of the systems involved in balance is responsible for the patient's problem, and his or her ability to maintain balance with incorrect and/or reduced sensory information. The test comprises six conditions, which are repeated three times in order to calculate the average result. Each condition is tested for 20 s. The different conditions are summarised below:

- Condition 1: stable surface and visual environment, eyes open.
- Condition 2: stable surface, eyes closed.
- Condition 3: stable surface, eyes open, moving visual environment.
- Condition 4: moving surface, eyes open, fixed visual environment.
- Condition 5: moving surface, eyes closed.
- Condition 6: moving surface, eyes open, moving visual environment.

We analysed the following parameters:

- Balance score (0–100%): the arithmetical mean of the three test results for each condition.
- Average balance score (0–100%): the arithmetical mean of the scores obtained in the 18 sensorial organisation tests.
- Somatosensory input = (mean condition 2 score/mean condition 1 score) $\times$ 100
- Visual input = (mean condition 4 score/mean condition 1 score) $\times$ 100
- Vestibular input = (mean condition 5 score/mean condition 1 score) $\times$ 100
- Visual preference = [(condition 3 + condition 6)/(condition 2 + condition 5)] $\times$ 100; a measure of the patient's reliance of visual information, even when that information is incorrect.

With regards to the RWS tests, the patient (through a feedback mechanism) has to displace his or her centre of gravity (COG) following the pictogram on the screen, at three different speeds (slow, medium and fast) in antero-posterior and lateral plane. The test is used to analyse displacement speed and directional control. The other test (LOS) quantifies the patient`s ability to displace his or her COG to eight different spatial positions, displayed on the screen. The patient's movement and his/her location at different positions are charted. The variables analysed are reaction time, mean velocity, directional control and the average distance covered in the first attempt to reach the most distant target.

The patients assigned to OKN treatment underwent five sessions on consecutive days. They stood, with their feet symmetrically positioned, in a dark room, 2 m from the wall displaying the optokinetic stimulus generated by the planetarium. The speed is increased as the sessions progress (from 40°/s at the start to 100°/s at the end), the stimulation sessions lasted from 5 min (the first session) to 15 min (last session), and the stimulation planes are varied (starting with horizontal stimuli and progressively adding vertical and torsional stimuli).

The patients assigned to the CDP group underwent five sessions of approximately 15–20 min on consecutive days. The Smart Balance Master® program was used, with ten exercises per session, defined according to each patient's deficit (as previously shown in a postural study). We also progressively increased the difficulty of the exercises by increasing the limits of stability, reducing the time for each movement and changing the sensory conditions (visual surround and moving platform).

The person in charge of vestibular rehabilitation was neither of the two who assigned patients to groups and evaluated the treatment.

The statistical study was performed with the SPSS 17.0 software package for Windows. We checked for statistically significant differences in the patients of each group who underwent vestibular rehabilitation (before and after treatment) by the Wilcoxon test. The Mann–Whitney test was used to analyse the differences in the benefits of rehabilitation between each group's results. A variable is statistically significant when p is <0.05.

Results

In the SOT analysis in the OKN group of patients, there was a statistically significant improvement in average balance score and visual preference, while the improvement was close to statistical significance in the vestibular input ($p = 0.050$, Wilcoxon test) (Fig. 1a).

In the group of CDP patients, there were statistically significant improvements in the vestibular and visual input and in average balance score (Fig. 1b).

If we compare the groups regarding these improvements, we find greater benefit in visual preference in the OKN group ($p = 0.039$, Mann–Whitney test). In the CDP group, however, improvement was greater in the use of visual and vestibular information ($p = 0.030$ and $p = 0.044$, respectively, Mann–Whitney test). There are no significant differences in average balance score or the somatosensory input ($p > 0.05$, Mann–Whitney test).

The results of the RWS and LOS are shown in Table 2 (optokinetic stimulation) and Table 3 (dynamic posturography). Only in the CDP group do we find statistically significant improvements in different limits of stability parameters (distance covered and directional control). Comparing the groups, we find that CDP shows a greater benefit in distance covered in limits of stability ($p = 0.029$, Mann–Whitney test) and that the difference in favour of CDP is close to statistical significance in directional control of LOS

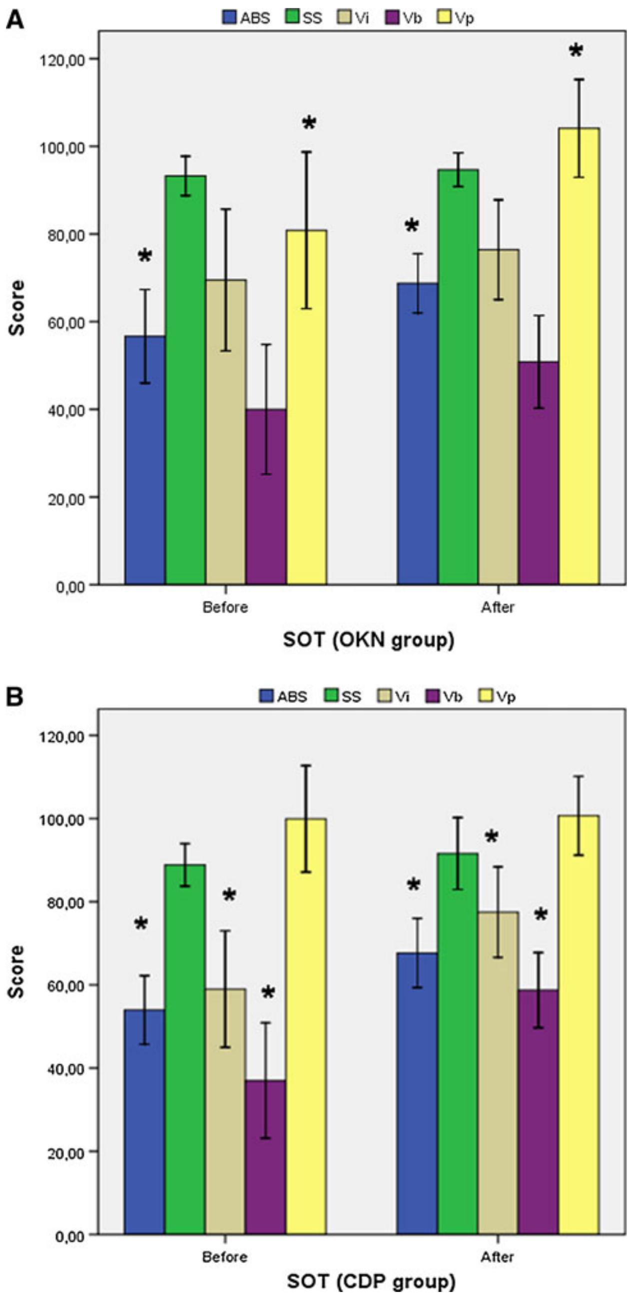

Fig. 1 **a** Mean scores before and after SOT sensory analysis treatment in the OKN group of patients (*ABS* average balance score, *SS* somatosensory input, *Vi* visual input, *Vb* vestibular input, *Vp* visual preference). The *error bars* represent the 95% confidence interval for the mean. Significant differences are indicated by *asterisks* [average balance score and visual preference ($p = 0.005$ and $p = 0.007$, respectively, Wilcoxon test)]. The improvement in the use of vestibular information is close to statistical significance ($p = 0.050$, Wilcoxon test). **b** Mean scores before and after SOT sensory analysis treatment in the CDP group of patients (*ABS* average balance score, *SS* somatosensory input, *Vi* visual input, *Vb* vestibular input, *Vp* visual preference). The *error bars* represent the 95% confidence interval for the mean. Significant differences are indicated by *asterisks* [average balance score and visual and vestibular input ($p = 0.005$, $p = 0.008$ and $p = 0.003$, respectively, Wilcoxon test)]

Table 2 RWS and LOS tests in the OKN group (before and after rehabilitation)

Variable	OKN group		*p*
	Before	After	
P. Displacement CG			
Antero-posterior			
Velocity (grad s^{-1})	2.93 (0.70)	2.96 (0.44)	0.779
DC[a] (%)	79.5 (7.52)	80.25 (7.24)	0.753
Lateral			
Velocity (grad s^{-1})	4.51 (1.28)	4.52 (0.59)	0.753
DC[a] (%)	86.75 (3.45)	87.25 (2.37)	0.334
Limits of stability			
Reaction time (s)	0.98 (0.20)	0.95 (0.313)	0.726
Velocity (grad s^{-1})	2.41 (0.548)	2.28 (0.66)	0.234
Distance (%[b])	57.37 (8.45)	59.12 (6.49)	0.610
DC[a] (%)	74.00 (6.76)	76.25 (6.49)	0.325

[a] Mean directional control

[b] Percentage of theoretical maximum

Mean scores with standard deviation in brackets

CG centre of gravity, *DC* directional control

Table 3 RWS and LOS tests in the CDP group (before and after rehabilitation)

Variable	CDP group		*p*
	Before	After	
P. Displacement CG			
Antero-posterior			
Velocity (grad s^{-1})	3.17 (1.00)	3.08 (0.55)	0.878
DC[a] (%)	79.41 (8.49)	82.0 (7.17)	0.286
Lateral			
Velocity (grad s^{-1})	4.04 (1.47)	5.07 (0.52)	0.065
DC[a] (%)	83.58 (5.61)	85.41 (5.90)	0.385
Limits of stability			
Reaction time (s)	0.93 (0.299)	0.81 (0.30)	0.230
Velocity (deg s^{-1})	3.10 (1.506)	2.98 (0.96)	0.656
Distance (%[b])	59.16 (11.90)	67.16 (7.82)	**0.003**
DC[a] (%)	68.33 (19.99)	82.16 (5.98)	**0.013**

[a] Mean directional control

[b] Percentage of theoretical maximum

Mean scores with standard deviation in brackets. Statistically significant differences are in bold print

CG centre of gravity, *DC* directional control

and velocity in the lateral plane of RWS ($p = 0.066$ in both, Mann–Whitney test).

In CDP rehabilitation patients, the DHI was 61.27 (SD 21.19) at baseline and 52.9 (SD 27.47) after rehabilitation. This difference was not statistically significant ($p = 0.075$, Wilcoxon test). In the OKN group, the DHI was 59 (SD 19.89) at baseline and 48.83 (SD 28.41) after rehabilitation, and improvement that likewise was not statistically significant ($p = 0.238$, Wilcoxon test). There were no significant differences between the two techniques in improving DHI ($p > 0.05$, Mann–Whitney test).

Discussion

Different studies have shown that vestibular rehabilitation with both CDP [12] and OKN [13] is effective in patients with instability of different aetiology. There is no evidence, however, of which is the optimal strategy for each patient.

Although there are studies showing that the best results are obtained by combining vestibular rehabilitation sessions with an exercise programme at home [14] (as the latter reinforces the treatment provided in the clinic), we decided not to perform at-home exercises in this experimental study, as we were unable to ensure that they were indeed performed or performed correctly, which could bias our assessment of the benefits of the two treatments.

As one of the methods of evaluation was also a rehabilitation technique (CDP), we decided to perform the post-treatment examination 3 weeks later in order to prevent the "learning" bias described by other authors [15].

One initially surprising finding was that, in spite of the improvements in balance found in CDP after rehabilitation, there were no significant benefits in the patient's short-term subjective perception. This has also been reported by other investigators [16, 17].

As previously published [2], we found that the two rehabilitation techniques are effective in the short term for improving balance in patients with chronic unilateral peripheral disorders. There are, however, some differences between them:

- With CDP, we can develop exercises to stimulate the hypofunctional sensory system, so we can expect to find more evident benefits in the use of vestibular and visual information. With the help of visual biofeedback, we can also increase limits of stability, thus reducing the risk of falls.
- Exposure to OKN equals vestibulo-ocular reflex asymmetries. In patients with poor visual preference (who find it difficult to control their balance in circumstances where visual input is imprecise and inconsistent with vestibular or somatosensory input), it reduces their hyper-reactivity to visual movement and visuo-vestibular conflict [18] by enhancing habituation mechanisms. With the required training, the central nervous system is capable of correctly resolving this sensory conflict and balance is recovered.

A limitation of the study is that the rehabilitation techniques have different lengths in the first sessions; however, this fact shows us that the optokinetic stimulation is equally effective with less time allocated.

As prior studies show that customised exercises are more effective than generic programmes [19], we need to define the optimal strategy in each patient.

We believe that patients with poor average balance score due to the incorrect use of vestibular and visual information would benefit more from a CDP exercise protocol. This also applies to patients with reduced limits of stability who are, therefore, at risk of falling.

On the other hand, patients with poor average balance score due to poor visual preference are ideal candidates for rehabilitation with OKN.

In any event, in spite of these differences, the two rehabilitation techniques are useful for improving balance in patients with chronic instability of unilateral vestibular origin.

Conflict of interest The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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