ORIGINAL ARTICLE

Foam Posturography: A Cheaper Way to Analyze Postural Stability in Peripheral Vestibular Disorders

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Objective: The aim of this study was to assess the diagnostic accuracy of static posturography with the foam rubber in unilateral and bilateral vestibulopathy in addition to the gait tests.

Methods: The study included 62 patients with peripheral vestibulopathy (unilateral n:41, bilateral n:21) and 45 healthy controls. Neurological and neurotological examinations including tonal audiometry, caloric tests and static posturography [mean center of gravity (COG) sway velocity, shift in COG alignment, tandem walk (step width, walking speed, and end sway velocity)] were performed in all patients.

Results: When compared with healthy individuals, COG sway velocity of the foam posturography [(Foam) Eyes Open and Closed)] and the step width in the tandem walk test was found to be statistically increased both in patients with uni- and bilateral peripheral vestibulopathy ($p<0.05$). The shift in COG alignment (degrees) in mediolateral and antero-posterior directions of the patients with uni- and bilateral vestibulopathy was not significantly different from the shift recorded in healthy controls ($p>0.05$).

Conclusion: Static posturography with foam rubber is valuable for demonstrating balance impairments in peripheral vestibular disorders. However, a significant shift to the affected side in unilateral or a shift in the antero-posterior direction in bilateral vestibulopathy may not be found especially after the acute phase.

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Introduction

Information from the three sensory systems—visual, vestibular and proprioceptive—is used for maintaining balance [1]. Disorders of the vestibular system are characterized by gaze impairment and head instability, which are associated with an upright posture deficit [2]. Posturography has been used for the objective and quantitative assessment of balance and for understanding the physiology and pathophysiology of postural contro[3,4]. In order to distinguish different sensory inputs involved in the maintenance of balance, dynamic posturography that uses a moving platform has been developed for the selective manipulation of visual and somatosensory inputs. An increase in body sway, which is measured while the individual stands on a moving platform with eyes closed, is considered specific to vestibular disorders [5]. However, two meta-analyses have shown an overall sensitivity and specificity of about 50% for both static and dynamic posturography with regard to vestibular patients [6, 7]. A recent study on current balance tests has also found that the computerized dynamic posturography sensory organization test has moderate sensitivity and specificity in patients with vestibular impairment [8].

A layer of foam rubber placed on the static posturography device can be a much cheaper alternative

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to dynamic posturography. In addition to the administration of gait tests, the aim of this study was to assess the diagnostic accuracy of static posturography with foam rubber in unilateral and bilateral vestibulopathy.

Methods

The study protocol was approved by the local ethics committee and informed consent was obtained from all participants. The study was conducted in the specialized neurotology clinic at the Ege University Medical School Department of Neurology, İzmir, Turkey. From January 2004 to January 2006, 62 patients with the diagnosis of peripheral vestibulopathy were enrolled in the study (unilateral n: 41; bilateral n: 21). The diagnoses of the 41 (21 right sided and 20 left sided) unilateral peripheral vestibulopathy (UPV) patients were as follows: Meniere's disease (n: 12); vestibular migraine (n: 11); vestibular neuritis (n: 9); sudden deafness with vestibular dysfunction (n: 2); and unknown (n: 7). Twenty-one patients were diagnosed with bilateral peripheral vestibulopathy (BPV), which included etiologies of drug toxicity (n: 5), bilateral Meniere's disease (n: 3), immune-mediated inner ear disease (n: 1), bilateral vestibular neuritis (n: 1), and unknown (n: 11). The estimated period between the onset of balance disorder and posturographic recording was 15 to 30 days in 7 patients, 1 to 3 months in 5 patients, 3 to 6 months in 12 patients, more than 6 months in 31 patients, and not clear in 7 patients. Forty-five age-matched healthy subjects with no history of vestibular attacks or migraine served as the control group. In order not to influence the vestibular function testing, subjects with other medical, neurological, or orthopedic conditions were excluded.

All patients had a detailed neurotological examination, which included examination of stance and gait in addition to the examination of eye movements and positional tests, which consisted of the Dix-Hallpike and roll maneuvers. The eye movements were recorded monocularly by video-oculography during these tests (Visual Eyes 4 channel VOG; Micromedical Technologies, Chatham, IL, USA). Also recorded were spontaneous eye movements in darkness with the non-recorded eye fixating and without fixation, saccadic, pursuit, and optokinetic eye movements. All patients underwent pure-tone audiometry and bithermal caloric tests using air calorics (since some patients had perforation in the external auditory canal, air calorics was preferred in order to maintain standardization). The ICS air caloric stimulator model NCA-200 (ICS, Schaumburg, IL, USA) was used for the caloric tests with an air flow of 8 l/min at 25°C and 50°C within 60 s. Maximum slow phase velocity (SPV) was determined using the ICS velocity computer system. In the absence of signs of central nervous system involvement, the diagnosis of UPV was made when a side difference >25% was present. Maximal SPV of nystagmus for cold plus warm caloric stimulus not exceeding 12°/s was accepted as the feature of BPV.

Static posturography was performed using the NeuroCom System Version 8.0.3 (NeuroCom International Inc., Clackamas, OR, USA). In order to avoid possible interference due to caloric testing, posturography was performed at least two hours after the caloric examination. The mean center of gravity (COG) sway velocity (deg/s) was recorded during four different conditions: on a static platform with eyes open (firmeo) and closed (firmec); and on foam with eyes open (foameo) and closed (foamec). Each test consisted of three trials with the same duration of 10 s. All patients were asked to stand upright as steadily as possible during these test conditions. The mean sway velocities recorded during the three trials were taken into consideration.

The second step was to measure the shift in COG alignment (deg) in mediolateral and antero-posterior directions during the four different conditions (firmeo, firmec, foameo, foamec). The mean shift of the three trials for the four conditions was again taken into consideration, and the percentages of patients showing shift to right, left, and back and forth were calculated.

Dynamic balance was tested by a tandem walk test. The subjects were asked to stand heel-to-toe in the starting position. When the "Go-" instruction appeared on the screen, they tandem walked as quickly as possible through the platform, which was 150 cm long and 45 cm wide, and held steady at the end of the platform. Walking speed (cm/s), step width (cm), and end sway velocity (deg/s) were measured three times and the mean values of these three trials were taken into consideration.

Statistical Methods

SPSS 20 for Windows was used for the statistical analysis. Hypothesis tests were performed at the significance level of α: 0.05 (means $p<0.05$ were accepted as significant). The Shapiro-Wilk test was performed to check if the data were normally distributed.

Because none of the parameters was normally distributed, nonparametric methods were used. Multiple group analyses were performed with the Kruskal-Wallis test. The Mann-Whitney test was used to compare the two groups. For the parameters that showed significant differences between patients and healthy controls, we constructed a receiver operating characteristics analysis (ROC) curve, in which the sensitivity was represented on the abscissa and the value of (1-specificity) was given on the ordinate. The areas under the ROC curve (AUC) were then calculated to determine the most useful parameters. A chi-square test was used to analyze the categorical variables between the groups.

Results

The mean age of the patients was 48.72±13.48 years; 65.4% of them were female. The mean age of the healthy controls was 46.5±16.4 years; 59.2% of them were female. The results of all tests performed are shown in Table 1. The comparison between the COG sway velocities recorded in the patient groups and the results of the healthy controls showed a statistically significant difference for the sway velocities recorded on foam with both eyes open (p: 0.03) and closed (p: 0.01). The dynamic balance test revealed a statistically significant increase in step width (p: 0.02) in the patient groups, whereas walking speed (p: 0.07) and end sway velocity values (p: 0.4) were not statistically different from the healthy controls. The individual comparison of the UPV and BPV groups with the healthy controls showed that COG sway velocity on foam with both eyes open and closed was significantly increased in both groups (foam eyes open for UPV p: 0.033; for BPV p: 0.001; foam eyes closed for UPV p: 0.046; for BPV p: 0.001) as well as the step width (for UPV p: 0.003; for BPV p: 0.008) (Figure 1). To compare their diagnostic utilities, we constructed ROC curves for

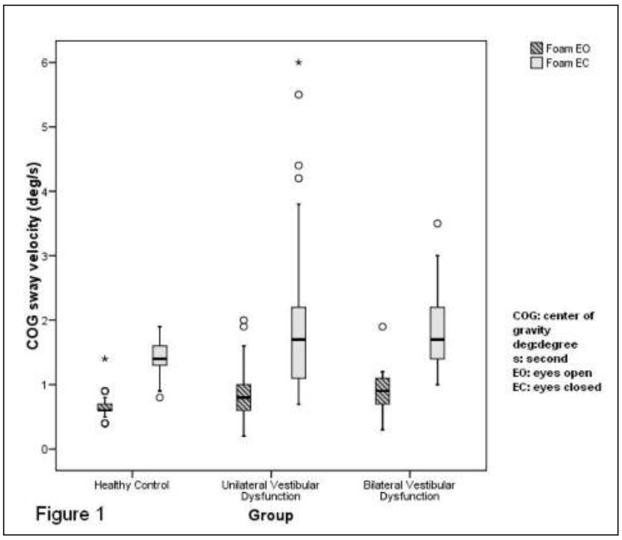

Figure 1. Center of gravity (COG) sway velocity on foam with eyes open (EO) and eyes closed (EC) among healthy controls and patients with uni- and bilateral vestibular dysfunction.

Table 1. Results of the posturographic analyses

Median [min-max]	Group 1 Healthy controls N: 45	Group 2 Unilateral peripheral vestibulopathy N:41	Group 3 Bilateral peripheral vestibulopathy N:21	p
Firm eo (d/s)	0.2[0.1-0.5]	0.2[0-1.1]	0.2[0.1-0.5]	0.1
Firm ec (d/s)	0.3[0.1-0.6]	0.3[0-1.7]	0.3[0.2-1.9]	0.6
Foam eo (d/s)	0.6[0.4-1.4]	0.8[0.2-2] p’: 0.033	0.9[0.8-1.9] p’: 0.001	0.03
Foam ec (d/s)	1.4[0.8-1.9]	1.7[0.7-6] p’: 0.046	1.7[1-3.5] p’: 0.001	0.01
Step width (cm)	6.8[4.1-1.9]	7.4[4.1-13.4] p’: 0.003	7.6[5.8-13] p’: 0.008	0.02
Walking speed (cm/s)	22.3[10.7-35.3]	18.5[3.4-33.8]	20.2[6.6-30.9]	0.07
Sway (d/s)	4.3[1.5-10.1]	3.7[1.5-9.6]	4.6[2.8-8.6]	0.4

Firm eo: Standing on firm ground with eyes open. Firm ec: Standing on firm ground with eyes closed. Foam eo: Standing on foam with eyes open. Firm ec: Standing on foam with eyes closed.

d: degree, s:second

p: comparison of the healty controls and the patient groups

p’: comparison of the healthy controls individually with unilateral and bilateral peripheral vestibulopathy groups

COG sway velocity (foam eyes open/eyes closed) and calculated their AUCs. An AUC of 1.0 represents a perfect test; an AUC of 0.5 represents an uninformative test. The AUCs of velocity and area in the foam/eyes closed were relatively large for BPV (Table 2). The sensitivity and specificity of each parameter are listed in Table 2.

Tables 3 and 4 show the percentages of patients with right or left-sided UPV and patients with BPV as well as the healthy controls with shifts in COG alignment in right, left, and back and forth directions. Comparison of the percentages of patients with UPV and BPV showing shifts in COG alignment with the percentages of healthy controls with shifts yielded no statistically significant difference (p>0.05) (Figures 2 and 3).

Discussion

In this study, static posturography with foam rubber was shown to be a valuable tool in demonstrating balance impairment in peripheral vestibular disorders. However, the expected COG alignment shift to the affected side in patients with UPV or a shift in the antero-posterior direction in patients with BPV could not be detected.

Whether dynamic posturography or foam posturography is useful in the clinical diagnosis of peripheral vestibular disorders remains controversial. The sensory organization test of dynamic posturography showed a change in sensitivity from 15% to 63% in detecting peripheral vestibular dysfunction in different studies [9-14]. The specificity of the test was reported to range from 34% to 95% [11, 13]. Some recent studies suggested that

Table 2. Comparison of posturographic variables between healthy controls and patients with unilateral/bilateral peripheral vestibulopathy

	Group 1		Group 2	
	Foam EO	**Foam EC**	**Foam EO**	**Foam** EC
AUC	0.63	0.62	0.73	0.76
95%CI	0.51-0.75	0.49-0.76	0.58-0.87	0.63-0.90
Cut-off value	0.65	1.45	1.45	0.75
Sensitivity	0.58	0.59	0.71	0.76
Specificity	0.55	0.64	0.64	0.78
p	0.04	0.04	0.003	0.001

Firm eo: Standing on firm ground with eyes open. Firm ec: Standing on firm ground with eyes closed . Foam eo: Standing on foam with eyes open. Firm ec: Standing on foam with eyes closed

CI: Confidence interval, AUC: area under the curve

Group 1: Unilateral vestibular dysfunction

Group 2: Bilateral vestibular dysfunction

Table 3. Percentages of healthy controls and patients showing COG alignment shift in right/left directions

	Group 1		Group 2a		Group 2b		Group 3		p
%	R	L	R	L	R	L	R	L	
Firm eo	63.6	36.4	52.6	47.4	45	55	42.9	57.1	0.21
Firm ec	53.5	46.5	60	40	44.4	55.6	42.9	57.1	0.7
Foam eo	75.0	25	77.8	22.2	71.4	26.6	60	40	0.4
Foam ec	75.0	25.0	73.7	26.3	63.2	36.8	57.9	42.1	0.4

Firm eo: Standing on firm ground with eyes open. Firm ec: Standing on firm ground with eyes closed . Foam eo: Standing on foam with eyes open. Firm ec: Standing on foam with eyes closed

Group 1: Healthy Controls

Group 2 a: Left vestibular dysfunction

Group 2b: Right vestibular dysfunction

Group 3: Bilateral vestibular dysfunction

p: comparison of the healty controls and the patient groups

R: right, L: left

Table 4. Percentages of healthy controls and patients showing COG alignment shift back/forth directions

	Group 1		Group 2a		Group 2b		Group 3		p
%	F	B	F	B	F	B	F	B	
Firm eo	27.3	72.4	35.3	64.7	55	45	30	70	0.7
Firm ec	26.7	73.3	45	55	44.4	56.6	23.8	76.2	0.14
Foam eo	77.3	22.7	80.0	20.0	81.0	19.0	66.7	33.3	0.5
Foam ec	65.9	34.1	95	5	80	20	66.7	32.3	0.06

Firm eo: Standing on firm ground with eyes open. Firm ec: Standing on firm ground with eyes closed . Foam eo: Standing on foam with eyes open. Firm ec: Standing on foam with eyes closed

Group 1: Healthy controls

Group 2 a: Left vestibular dysfunction

Group 2b: Right vestibular dysfunction

Group 3: Bilateral vestibular dysfunction

p: comparison of the healthy controls and the patient groups

F: forth, B: back

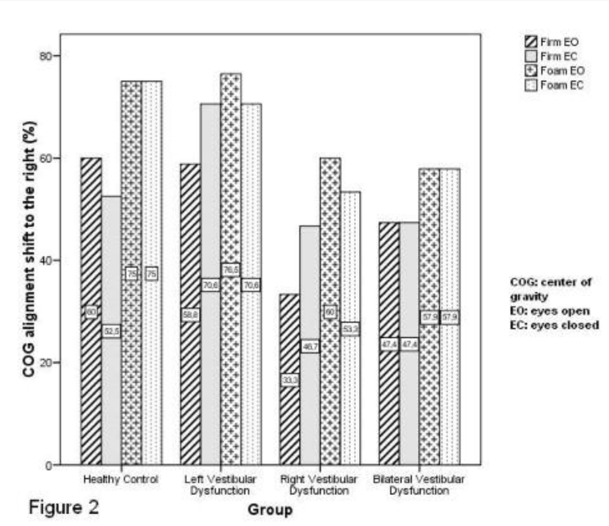

Figure 2. The Center of gravity (COG) alignment shift to the right percentages on firm surface eyes open (Firm EO), on firm surface eyes closed (Firm EC), on foam eyes open (foam EO), and on foam eyes closed (foam EC) among healthy controls and patients with uni- and bilateral vestibular dysfunction.

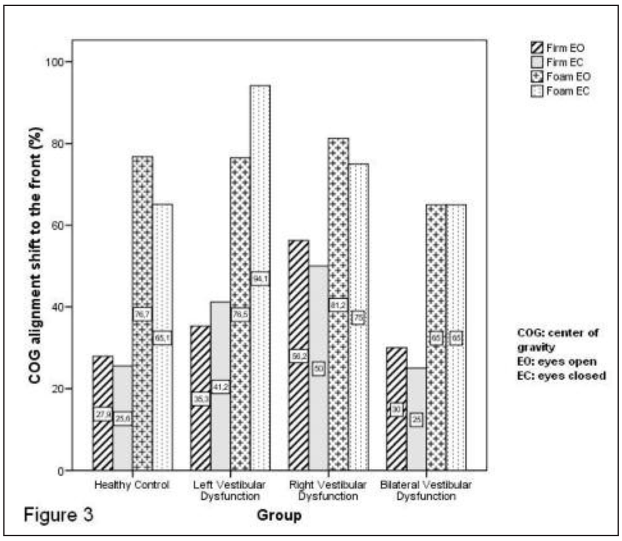

Figure 3. The Center of gravity (COG) alignment shift to the front percentages on firm surface eyes open (Firm EO), on firm surface eyes closed (Firm EC), on foam eyes open (foam EO), and on foam eyes closed (foam EC) among healthy controls and patients with uni- and bilateral vestibular dysfunction.

dynamic posturography is not useful for identifying patients with chronic unilateral vestibulopathy, but it is modestly useful for identifying patients with acute bilateral or acute severe unilateral vestibulopathy [15, 16]. Stance with eyes open and closed has been studied in static platform posturography, with a reported sensitivity of below 50% [17]. Recent studies using foam posturography provided promising results in patients with unilateral and bilateral peripheral vestibulopathy[18,19]. Romberg's ratio of velocity was reported to have a sensitivity of 79% and specificity of 80% [18].

Our patients with UPV and BPV had impairment in balance, which was indicated by a greater sway velocity recorded on a foam surface. The sway velocity further increased when the eyes were closed, which means the patients were unable to maintain postural balance in conditions when visual information was unavailable, proprioceptive information is inaccurate, and postural control relies mostly on vestibular cues. Like previous studies, the present study also found that the COG sway velocity on foam (with eyes open and eyes closed) has a sensitivity and specificity of the upper 50% both in UPV and BPV.

The COG alignment shift in our patient groups showed no difference from the shift recorded in the healthy controls. In acute UPV, the initial perception of apparent body motion is directed away from the side of the lesion, and the postural reactions initiated by vestibulospinal reflexes are usually in a direction opposite to the direction of vertigo, which results in a Romberg fall toward the side of the lesion. In patients with BPV, measurements of postural instability show the largest amplitude in the fore-aft direction corresponding to the predominant direction of fall. Sideways falls have also been reported [20]. However, in our study, the percentage of patients with right-sided UPV showing right-sided shifts in COG alignment was not different from the percentage of healthy controls with right-sided shift. Patients with left-sided UPV showed the same results. Similarly, the percentage of patients with BPV showing COG alignment shift in fore-aft or lateral directions was the same as the percentage of healthy controls with shifts in the same directions. These results might be due to a delay between the onset of the balance disorder and the posturograpic recordings in most of our subjects. After peripheral vestibular damage, the recovery process known as compensation starts to rearrange signals in the central nervous system in order to use information from the unaffected labyrinth as an adequate source for vestibulo-ocular and vestibulo-spinal reflexes [21]. Recovery of the damaged labyrinth also takes place in varying degrees [22, 23].

Another parameter taken into consideration in our study was the dynamic balance observed during the tandem walk test. Walking speed and end sway velocity values were within normal range, whereas step width was increased in both groups, indicating that these patients needed a wider base of support. Balance during locomotion requires that the input of the vestibular system in the head be integrated with the somatosensory input from the feet. It is well known that in acute peripheral vestibular lesions, patients are better off running than walking because an automatic spinal locomotor program suppresses destabilizing vestibular inputs while running [24]. Therefore, patients are not expected to walk slowly, which causes more impairment. The end sway velocity was also normal when the recordings were made during stance on the platform with eyes open, which supplied the subjects with accurate proprioceptive and visual information.

Dynamic posturographic studies have shown the recovery of postural sway within a few weeks after a unilateral vestibular lesion [25]. Although over 80% of our patients were tested after the third month, an increase in sway velocity was detected on foam. However, a COG shift to the affected side in patients with UPV or a more prominent fore-aft shift in patients with BPV could not be found. A wider-based gait was recorded and walking speed was unchanged as expected.

Though a static posturography can't replace dynamic posturography in detecting postural abnormalities which is an important limitation of our study we showed that it can still be used with the addition of a foam rubber in peripheral vestibular disorders when a dynamic posturography is not available. Our second limitation is the performance of the posturographic analyses during both subacute and chronic phases of the vestibular insult changing from two weeks to several months. Studies performed on more homogenous groups on the bases of disease duration would certainly give more accurate results.

Conflict Of Interest: None of the authors have a financial relationship with the organization that sponsored the research.

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