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Assessment of diagnostic accuracy of foam posturography for peripheral vestibular disorders: Analysis of parameters related to visual and somatosensory dependence

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ABSTRACT

Objectives: Simple tests to detect peripheral vestibulopathy might be practically useful before conducting elaborate examinations. The purpose of this study was to assess the diagnostic accuracy of foam posturography for peripheral vestibulopathy, with emphasis on visual and somatosensory dependence.
Methods: Two-legged stance tasks were conducted in patients with unilateral ($n = 68$) and bilateral ($n = 16$) vestibulopathy and healthy controls ($n = 66$), under four conditions; eyes open with and without the foam rubber, and eyes closed with and without the foam rubber.
Results: The values of six parameters; the velocity of movement of the center of pressure (COP) and envelopment area tracing by the movement of the COP in eyes closed/foam rubber, the Romberg's ratios of velocity and area with foam rubber, and the foam ratios (ratios of a measured parameter with to without the foam rubber), of velocity and area in eyes closed, were significantly higher in unilateral and bilateral vestibulopathy compared with the control ($p < 0.001$). The area under the receiver operating characteristic curve for the Romberg's ratio of velocity with the foam rubber was the largest.
Conclusions: Foam posturography detected high levels of visual and somatosensory dependence in patients with vestibulopathy.
Significance: Foam posturography is useful for preliminary assessment of possible peripheral vestibulopathy.

1. Introduction

The vestibular labyrinth located in the inner ear serves as a sensory organ for angular and linear movements. The semicircular canals (SCCs) respond to angular accelerations, whereas the otolith organs respond to linear accelerations. In the SCC system, the lateral semicircular canal (LSCC), the anterior semicircular canal (ASCC) and the posterior semicircular canal (PSCC) are at almost right angles to each other, and the system can sense angular acceleration in all directions. The otolith organs, which are composed of the utricle and saccule, operate as multidirectional linear accelerometers in the diverse polarization of the maculae.

Considering the complexity of the vestibular system, new tests are required for comprehensive evaluation of the function of the receptors in each vestibular end-organ. A number of tests, such as the caloric test and the vestibular evoked myogenic potential (VEMP) test, have been used in the differential diagnosis of vestibular disorders (Colebatch and Halmagyi, 1992; Murofushi et al., 1996, 2003; O'Neill, 1987). However, these tests are time-consuming and demand relatively hard physical tasks for patients. Preliminary tests for vestibular disorders prior to the conduct of detailed examination might be practical.

Posture in human is maintained by muscular actions governed by the processing of the central nervous system. The central processing integrates the information from vestibular, visual, and somatosensory inputs. Posturography measures the position of the center of pressure (COP), which is a good parameter of the position of the center of mass during upright stance. Static posturography measures spontaneous movements of the body on a firm platform (Black and Wall, 1981). Dynamic posturography (moving platform) or posturography while standing on a foam rubber (foam posturography) can change the relative contributions of the visual,

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somatosensory, and vestibular inputs, which are used to maintain upright posture under normal circumstances (Furman, 1995; Nashner, 1971; Nashner et al., 1982). Trunk angular sway measured with angular transducers is also used as a clinical test of balance disorder (Allum et al., 2001, 2002).

Previous studies reported that under the condition of standing on foam rubber, patients with unilateral or bilateral peripheral vestibular disorders show more severe balance deficits than healthy controls (Black et al., 1983; Baloh et al., 1998b; Allum et al., 2001). However, the tasks and parameters that can be used in preliminary and simple tests for the diagnosis of peripheral vestibular disorders remain controversial. Although posturography cannot directly evaluate the function of each vestibular end-organ (Baloh et al., 1998a–c, 1994), given it is easy to use and noninvasive, its adaptation for a preliminary test in balance disorders should be discussed in more detail.

The purpose of this study was to assess the diagnostic accuracy of the originally established posturography analysis system with the foam rubber for unilateral and bilateral peripheral vestibular disorders, especially noting the visual and somatosensory dependence in patients with peripheral vestibular damage. We calculated the sensitivity and specificity of several parameters used in foam posturography that could discriminate patients with peripheral vestibular damage from healthy subjects, as well as the construction of receiver operating characteristic (ROC) curve. The strength of this study lies in the validation of these criteria in an independent sample. Several factors threaten the validity of studies of diagnostic accuracy. This inspired the launch of the Standards for Reporting of Diagnostic Accuracy (STARD) initiative (Bossuyt et al., 2003a,b). The objective of the STARD initiative is to improve the quality of studies on diagnostic accuracy. The design of this study followed the guidelines set out in the STARD.

2. Methods

2.1. Participants

Subjects were recruited between December 8, 2006, and October 12, 2007 at the Balance Disorder Clinic, Department of Otolaryngology, the University of Tokyo Hospital. The study was approved by the local ethics committee and conducted according to the tenets of the Declaration of Helsinki, and an informed consent was obtained from each participant. Patients were scheduled to undergo caloric test prior to posturography. Both tests were performed on the same day. Caloric testing was performed as the reference standard by irrigating the external auditory canal with 2 ml ice water for 20 s followed by aspiration. Canal paresis (CP) was calculated as the difference between the maximal slow phase eye velocity for each ear irrigation divided by the sum of slow phase eye velocities. Peripheral vestibulopathy was diagnosed when any of the following two criteria of the caloric test was met: (i) CP percentage >20% (peripheral unilateral vestibulopathy) (Iwasaki et al., 2005); (ii) maximum slow phase eye velocity <7°/s bilaterally (peripheral bilateral vestibulopathy). All subjects with a known history of other neurological or orthopedic disorders, or other abnormal findings on a brief neurological examination, were excluded. Consecutive patients with peripheral vestibulopathy were enrolled after the caloric test. Healthy control subjects were selected from the staff of the University of Tokyo Hospital.

A total of 90 consecutive patients with peripheral vestibulopathy were enrolled after vestibular examination including caloric test. We considered 6 patients were unable to endure our study protocol due to difficulty in standing on hard floor in the upright posture eyes open and were excluded from the study. Thus, 84 patients were enrolled in this study [35 men, 49 women, mean (±SD) age, 57.4 (±13.9) years, range, 23–84]. Out of the 84 patients, 68 [26 men, 42 women, age, 57.7 (±14.0) years, range, 23–84] were diagnosed as unilateral vestibulopathy, including etiologies of vestibular neuritis ($n = 14$), acoustic tumor (pre-operative type, $n = 6$, post-operative type, $n = 6$), Meniere's disease ($n = 4$), sudden deafness with vestibular dysfunction ($n = 4$) and others ($n = 34$). The other 16 patients [7 men, 9 women, age, 56.4 (±13.9) years, range, 29–71] were diagnosed as bilateral vestibulopathy, including 10 patients who did not show any nystagmus bilaterally and 6 patients who showed nystagmus with maximum slow phase velocity less than 7°/s bilaterally. The mean age of the 66 healthy control subjects (22 men, 44 women) was 56.5 (±14.6) years (range, 24–79). The estimated period after the first episode of balance disorder was less than 14 days in 11 patients, 14–30 days in 13, 1–6 months in 16, ⩾6 months in 34, and not clear in 5 patients. The remaining 5 patients had no subjective episode of balance disorder.

2.2. Posturography test

We used Gravicorder G-5500 (Anima Corp., Tokyo) with foam rubber (Nagashima Medical Instruments, Tokyo). For posturography, we used vertical force transducers to determine instantaneous fluctuations in the COP at a sampling frequency of 20 Hz. A statokinesigram (i.e., the sway path of the COP) was obtained from these vertical forces as changes in electrical signals. The foam rubber material was made of natural rubber, with a tensile strength of 2.2 Kgf/cm^2, elongation stretch percentage of 100%, density 0.162 g/cm^2, and thickness of 5 cm. Two-legged stance tasks were performed under four conditions: eyes open with and without the foam rubber, and eyes closed with and without the foam rubber. In each of the four conditions, the distal ends of the big toes of the feet were positioned 45° apart with the heels of both feet close to each other (Fig. 1).

The recording time was 60 s or until the subject required assistance to prevent falling. In the eyes-open condition, the subjects were asked to watch a small, red circle 2 m away from where they were standing in a quiet, well-lit room. Before the test, care was taken to ensure that the platform was at resting level on the floor.

Posturography and caloric tests were administered and evaluated by eight otolaryngologists engaged in medical care at the Balance Disorder Clinic, Department of Otolaryngology, the University of Tokyo Hospital.

2.3. Statistical methods

The outcome measures were the mean velocity of movement of the COP for 60 s, which was termed "the velocity", and the envelopment area tracing by the movement of the COP, which was termed "the area". We measured these two variables under four conditions: eyes open with and without the foam rubber, and eyes closed with and without the foam rubber. We calculated the Romberg's ratios of the velocity and area, without and with the foam rubber. The Romberg's ratio was defined as the ratio of a measured value with eyes closed to that with eyes open. We also defined "the foam ratio" as the ratio of a measured value with the foam rubber to without the foam rubber. We calculated the foam ratio of the velocity and the area, with the eyes open and closed.

An overall test for difference among healthy controls, patients with unilateral vestibulopathy and those with bilateral vestibulopathy was performed for each variable using nonparametric Kruskal–Wallis test. The three groups were then compared in pairs for variables that showed a significant difference in Kruskal–Wallis test using nonparametric Steel–Dwass multiple-comparison method. We adopted the variables that showed significant difference between healthy controls and unilateral vestibulopathy patients, and between healthy controls and bilateral vestibulopathy patients, in the Steel–Dwass multiple-comparison method. For pa-