Vertigo Caused by Semicircular Canal and Otolith Lesions

Abstract: The anatomical location of vestibular disorders that cause vertigo is commonly diagnosed simply as “peripheral” or “central”. As one can easily imagine, there are many anatomical regions in the central nervous system that can give rise to vertigo. At least two anatomical locations where peripheral vestibular lesions cause vertigo are possible: the semicircular canals and the otolith. Moreover, the semicircular canals on each side consist of three canals, anterior, lateral, and posterior, and the otolith consists of two organs, the saccule and utricle. The existence of localized lesions in the labyrinth has been noticed very recently. Lateral canal benign paroxysmal positional vertigo is a good sample of a localized labyrinthine lesion. However, very little is known about methods of diagnosis of these lesions. A very powerful tool for diagnosing localized lesions is three-dimensional analysis of spontaneous or induced nystagmus. The velocity vector of the nystagmus allows identification of the anatomical source of the lesion, that generates the nystagmus.

Key words: Inner ear; Vertigo; Semicircular canals; Otoliths

Introduction

Vertigo may result from various causes. The symptom of vertigo may signify a problem in the inner ear and vestibular nerve, where sensory signals are received and then transmitted to the vestibular nuclei in the central nervous system. In addition, the cerebellum and the brainstem, where sensory information is integrated, play the important role for causing the symptom.

The inner ear in one side contains the sensors of balance and hearing. The sensors of balance comprise the three semi-circular canals (lateral, anterior, and posterior) which detect angular acceleration, and the otolith organs, namely the utricle and saccule, which monitor linear acceleration and the orientation of the head relative to gravity (Fig. 1). The inner ear lesions include entire or partial inner ear...
dysfunction, which may occur unilaterally or bilaterally.

Very recently, some clinicians became aware of the precise relationships between dysfunction of individual labyrinthine organs, and the clinical manifestations.

**Morphology and Function of the Semicircular Canals and Otoliths**

The bony labyrinth of the inner ear is a very dense shell that is filled with perilymph. Within the bony labyrinth, the membranous labyrinth filled with endolymph is located as the shape of bony labyrinth.

The vestibular labyrinth comprises the two otolith organs, and the three semicircular canals. The three semicircular canals, which detect angular acceleration, are so arranged almost in planes orthogonal to one another, as to detect angular acceleration. Each of the three semicircular canals has small swellings (ampullae) at one end. Each ampulla has a crista having sensory cells (hair cells) on its surface. In the crista, cilia arising from the hair cells are embedded in gelatinous material (cupula), which extends across the ampulla (Fig. 2). The movement of the endolymph during angular acceleration results in displacement of the cupula, stimulating the hair cells.

The sensor of the otolith organ, which comprises utricle and saccule, are called maculae. The utricle and saccule are set approximately at right angles. Both the utricular macula and saccular macula are covered with a gelatinous mass containing an otoconia (otolith), to which cilia from the hair cells are attached. When the head moves with linear acceleration, the otoconia lag behind and deflect the cilia, which produces a change in the sensory signals emitted by the hair cells (Fig. 3).
Vertigo Originating in the Semicircular Canals and/or Otoliths

Vertigo can be divided into two major categories: peripheral and central types. Meniere’s disease is characterized by a combination of symptoms, including severe episodes of vertigo, that are attributable to dysfunction of both the vestibular sensory organs and the auditory organ (cochlea).

On the other hand, there are diseases that may damage only a portion of the vestibular sensory organs to cause vertigo. Actually, it has been speculated that the pathology of benign paroxysmal positional vertigo (BPPV) comes from the impairment of the posterior semicircular canal. In this context, some investigators have proposed that BPPV of lateral semicircular canal type should be included as another category of vertigo.

How to Differentiate Vertigo of Semicircular Canal Origin from that of Otolith Origin

The functions of the semicircular canals can be tested clinically. They may be assessed by rotating a patient in a computer-controlled chair for creating angular acceleration to stimulate the endolymphatic flow (rotational test), or by irrigating the ear with cold or warm water (caloric test). The caloric test is especially useful for detecting semicircular canal dysfunction of one or the other side. However, it is not possible to test the functions of the individual semicircular canals by the caloric test. A recent study has shown that an analysis of eye movements induced by rapid rotation of the head on the target plane may be used to detect individual semicircular canal deficits (head impulse test).1)

In contrast, no reliable assessment methods for otolith functions are available. One of the tests that has been used is ocular counter-rolling, which is a test based on the observation that when the head of the patient is tilted to the right or to the left, the eyes tend to rotate in the opposite direction (counterclockwise and clockwise to the patient, respectively). However, the normal eye rotation angles are only 6° when the head is tilted 45° and measurements vary among patients. These features are not regarded as suitable for a daily clinical test.

Newer approaches for evaluation of otolithic functions include the off vertical axis rotation (OVAR) test (Fig. 4), subjective visual horizontal determination, and elicitation of vestibular evoked myogenic potentials (VEMPs) for estimating otolith functions from cervical muscle contractions evoked by intense acoustic stimuli.

In the OVAR test, the subject is seated on a chair in an enclosed large chamber. Nystagmus is observed while the chair is rotated around the vertical axis. After the nystagmus disappears at a constant velocity rotation, the rotational axis is tilted to various degrees to induce a new eye movement while continuing the rotary stimulation. The newly evoked nystagmus in this condition is recorded for analysis of the otolith functions, since the semicircular canals in this condition are no longer under stimulation.2)

The subjective visual horizontal determination may be a relatively simple test to assess otolith functions. The test is performed by asking subjects to fix the position of the head and...
to move the target luminous line set about 10° to the right or the left until the target line in a darkened room is viewed as horizontal. Deviation of the horizontal line is small in subjects with normal otolith functions, while in with a unilateral inner ear dysfunction, especially of the otoliths, the target line tilts toward the affected side. Similar results are obtained in the subjective visual vertical determination. As described above, subjective visual horizontal determination is easy to perform, but further studies are required to clarify the exact relationships between the test results and the affected site or severity of the disease.

VEMPs occurring in cervical muscles in response to intense acoustic stimuli of short duration (clicks) are considered to originate in the saccule. These responses can be obtained even in patients who are completely deaf, if they have normal saccular functions. Elicitation of VEMPs has, over a period of time, become popular as an otolith function test. Incorporation of some ingenuity in the procedure may enhance its usefulness as a routine clinical vestibular test.

Although these above mentioned tests can reveal impaired otolith functions, further improvements in the tests may not be easily accomplished, and confirming whether vestibular disorders arise from impairment in the semicircular canals or otoliths, remains a challenge in patients with vestibular organ dysfunction in the clinical setting. Data from patients with partial ablation of the inner ear, or those with congenital deficiency of the semicircular canals or otoliths could prove very helpful for improving the algorithms for these test procedures.

**Estimation of Partial Labyrinthine Dysfunction Based on Analysis of Eye Movements**

Acute lesion of the semicircular canals or otoliths causes disequilibrium and spontaneous nystagmus. Accordingly, accurate analysis of spontaneous nystagmus may be used to determine the anatomical localization of the affected site. In this context, electronystagmography (ENG), which has been performed for clinical diagnosis, records only horizontal and vertical eye movements, and is not appropriate for quantitative analysis of vestibular nystagmus commonly associated with rotatory eye movements.

Simultaneous three-dimensional analysis of eye movements (horizontal, vertical, and torsional) has a long history of research, but its clinical application is still new. At our institution, we developed a unique video image analysis system (VIAS) for analyzing otolithocular movements induced by OVAR and spontaneous nystagmus.

BPPV was previously attributed to otolithic dysfunction, but recent studies have emphasized the relationship between BPPV and impairment of function of the posterior semicircular canal. The vector of the slow phase velocity of the nystagmus obtained from three-dimensional analysis of positional nystagmus using our VIAS has been shown to be consistent with that of the semicircular canal in some patients with BPPV, and inconsistent with that of any semicircular canal in other patients with BPPV. Thus, BPPV may also be caused by impaired otolith function.

In addition, we carried out three-dimensional analysis of positional nystagmus in patients with BPPV of lateral semicircular canal type, which has recently been proposed as a category of vertigo. The results showed that BPPV in this category may also be classified into two types: of lateral semicircular canal origin and of otolithic origin. Therefore, detailed analysis of spontaneous or induced nystagmus would be useful for differentiating between semicircular canal and otolithic impairment in patients with vertigo.

**Conclusion**

We believe that vertigo is caused by not only
entire inner ear dysfunction, but also partial lesion. Further studies, however, are required to establish reliable test procedures to differentiate among impairments of individual sensory organs.

REFERENCES