However, we investigated the response during the early phase of stabilization (1–2 min after standing up) because the response has been commonly used in the clinical evaluation of neural circulatory control (Wieling and Lieshout 1997). We were able to find significant differences in the changes in BP responses even in the early phase of stabilization after standing up in the orthostatic Schellong test, which has been used in everyday practice. The increases in the HR after standing up were uniformly observed in all participants of this study. These results suggest that the significant drop in the BP after standing up is not the result of a decreased ability to produce compensatory HR responses. Further studies using the sequential beat-by-beat measurements of BP may detect a more severe drop in the BP after standing up in patients of the absent VEMP group. However, the clinical significance of our results for dizzy patients remains unclear, because there was no significant difference in the score on the DHI among the three groups.

The male patients in the absent VEMP group showed a significant drop in their DBP at 1 min after standing up; however, no significant change was noted in the DBP at 1 min after standing up in the asymmetry VEMP and the absent VEMP groups. A clinical study demonstrated that the symptoms associated with unilateral otolith dysfunction may be more swiftly compensated in comparison with dysfunction of the lateral semicircular canal (Hafstrom et al. 2004). The effects due to disorders of the vestibular-cardiovascular reflex in the asymmetry VEMP group might also be rapidly compensated. Patients with bilateral vestibular dysfunction often suffer from continuing symptoms because of the vestibular decompensation. Our results may therefore indicate that the bilateral disorders of otolith organs may greatly influence the initial BP control during posture transition for long time relatively (Yates et al. 1999), thus resulting in the occurrence of either lightheadedness or fainting when standing up rapidly.

Ray demonstrated that there was no gender difference in the vestibulosympathetic reflex since sympathetic activation during head-down rotation in the prone posture was similar in males and females. We herein considered the gender difference for the following reasons. First, the SBP of female patients in the absent VEMP group tended to decrease at 1 min after standing up, but the difference was not significant. We speculated that some female patients might stand up more slowly to avoid transient OH in comparison with male patients since females generally have greater orthostatic intolerance due to their decreased responsiveness in terms of the mechanisms that underlie BP regulation under orthostatic challenge. Therefore, it is possible that the compression of the venous vessels in the contracting muscle of the legs due to the effort of standing in females is weaker than that in males, resulting in a smaller transient initial decrease in the arterial BP by standing up in females. Second, there were no significant differences in the average SVV and CP% among the three female groups classified based on the amplitude of the VEMP. The gender difference in the VEMP responses has not been reported. Our results therefore suggest that the vestibular dysfunction in female patients might be well compensated for or might possibly be small regarding the extension of the lesions in the vestibular organs and/or nerves, resulting in that the BP response of female patients in the absent VEMP group was similar to that of female patients in the normal VEMP group. In addition, the BP regulation is altered by the menstrual cycle (Dunne et al. 1991). However, our study did not control for the menstrual cycle in female patients; therefore, our results may have been different if the menstrual cycle in the female patients had been strictly controlled.

The criteria for OH were fulfilled in 19.6% of patients in the absent VEMP group, which was significantly greater than the positive ratio for OH in the normal VEMP group. Our results therefore support the hypothesis that graviceptive disorders due to dysfunction of otolith organs may provoke OH. Patients with vestibular damage often complain of light-headedness and unsteadiness upon rapid motion, and these symptoms have been thought to be due to vestibular-ocular or vestibular-spinal reflex disorder. In addition, the elderly often complain of symptoms associated with OH, which have been explained by a decline of venous return associated with muscle weakness, the decrease in fluid volume, the increase of venous compliance, dysfunction of the baroreflex and the degradation of cardiac performance (Rutan et al. 1992). The otolith organs are vulnerable to degradation due to aging, and the vestibular-cardiovascular response may be diminished with age (Ray and Monahan 2002; Tanaka et al. 2009). Clinical physicians should therefore consider that lightheadedness and fainting when standing up may be associated with hypofunction of the vestibular-cardiovascular reflex due to an otolith disorder. Although further studies are needed to evaluate the precise mechanism, we believe that the presence of a graviceptive disorder due to disease and/or advanced age may induce OH.

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References

Aoki M, Burchill P, Yates B, Golding JF, Gresty MA (2000) Graviceptive control of blood pressure in man. Arch Ital Biol 138:93–97

Colebatch JG, Halmagyi GM, Skuse NF (1994) Myogenic potentials generated by a click-evoked vestibulocollic reflex. J Neurol Neurosurg Psychiatry 57:190–197

Convertino VA (1998) Gender differences in autonomic functions associated with blood pressure regulation. Am J Physiol 275:R1909–R1920

Doba N, Reis DJ (1974) Role of the cerebellum and the vestibular apparatus in regulation of orthostatic reflexes in the cat. Circ Res 40:9–18

Dunne FP, Barry DG, Ferriss JB, Grealy G, Murphy D (1991) Changes in blood pressure during the normal menstrual cycle. Clin Sci (Lond) 81:515–518

Essandoh LK, Duprez DA, Shepherd JT (1988) Reflex constriction of human limb resistance vessels to head-down neck flexion. J Appl Physiol 64:767–770

Freeman R, Wieling W, Axelrod FB, Benditt DG, Benarroch E, Biaggioni I, Cheshire WP, Chelimsky T, Cortelli P, Gibbons CH, Goldstein DS, Hainsworth R, Hilz MJ, Jacob G, Kaufmann H, Jordan J, Lipsitz LA, Levine BD, Low PA, Mathias C, Raj SR, Robertson D, Sandroni P, Schatz IJ, Schondorf R, Stewart JM, van Dijk JG (2011) Consensus statement on the definition of orthostatic hypotension, neurally mediated syncope and the postural tachycardia syndrome. Auton Neurosci 161:46–48

Friedmann G (1970) The judgement of the visual vertical and horizontal with peripheral and central vestibular lesions. Brain 93:313–328

Gotshall RW (2000) Gender differences in tolerance to lower body negative pressure. Aviat Space Environ Med 71:1104–1110

Gotshall RW, Tsai PF, Frey MA (1991) Gender-based differences in the cardiovascular response to standing. Aviat Space Environ Med 62:855–859

Gresty MA, Bronstein AM, Brandt T, Dieterich M (1992) Neurology of otolith function: peripheral and central disorders. Brain 115(Pt 3):647–673

Hafstrom A, Fransson PA, Karlberg M, Magnusson M (2004) Idiosyncratic compensation of the subjective visual horizontal and vertical in 60 patients after unilateral vestibular deafferentation. Acta Otolaryngol 124:165–171

Hordinsky JR, Gebhardt U, Wegmann HM, Schafer G (1981) Cardiovascular and biochemical response to simulated space flight entry. Aviat Space Environ Med 52:16–18

Jacobson GP, Newman CW (1990) The development of the dizziness handicap inventory. Arch Otolaryngol Head Neck Surg 116:424–427

Jian BJ, Cotter LA, Emanuel BA, Cass SP, Yates BJ (1999) Effects of bilateral vestibular lesions on orthostatic tolerance in awake cats. J Appl Physiol 86:1552–1560

Kaufmann H, Biaggioni I, Voustianiouk A, Diedrich A, Costa F, Clarke R, Gizzi M, Raphan T, Cohen B (2002) Vestibular control of sympathetic activity: an otolith-sympathetic reflex in humans. Exp Brain Res 143:463–469

Lee IS, Park HJ, Shin JE, Jeong YS, Kwak HB, Lee YJ (2009) Results of air caloric and other vestibular tests in patients with chronic otitis media. Clin Exp Otorhinolaryngol 2:145–150

Normand H, Etard O, Denise P (1997) Otolithic and tonic neck receptors control of limb blood flow in humans. J Appl Physiol 82:1734–1738

Ray CA (2000) Effect of gender on vestibular sympathoexcitation. Am J Physiol Regul Integr Comp Physiol 279:R1330–R1333

Ray CA, Carter JR (2003) Vestibular activation of sympathetic nerve activity. Acta Physiol Scand 177:313–319

Ray CA, Hume KM (1998) Neck afferents and muscle sympathetic activity in humans: implications for the vestibulosympathetic reflex. J Appl Physiol 84:450–453

Ray CA, Monahan KD (2002) Aging attenuates the vestibulosympathetic reflex in humans. Circulation 105:956–961

Rutan GH, Hermanson B, Bild DE, Kittner SJ, LaBaw F, Tell GS (1992) Orthostatic hypotension in older adults: the cardiovascular health study—CHS collaborative research group. Hypertension 19:508–519

Su HC, Huang TW, Young YH, Cheng PW (2004) Aging effect on vestibular evoked myogenic potential. Otol Neurotol 25:977–980

Tanaka K, Abe C, Awazu C, Morita H (2009) Vestibular system plays a significant role in arterial pressure control during head-up tilt in young subjects. Auton Neurosci 148:90–96

Vibert D, Hausler R, Safran AB (1999) Subjective visual vertical in peripheral unilateral vestibular diseases. J Vestib Res 9:145–152

Welgampola MS, Colebatch JG (2005) Characteristics and clinical applications of vestibular-evoked myogenic potentials. Neurology 64:1682–1688

Wieling W, Lieshout JJ (1997) Maintenance of postural normotension in humans. In: Low P (ed) Clinical autonomic disorders, 2nd edn. Lippincott-Raven, Philadelphia, pp 73–82

Wieling W, Krediet CT, van Dijk N, Linzer M, Tschakovsky ME (2007) Initial orthostatic hypotension: review of a forgotten condition. Clin Sci (Lond) 112:157–165

Woodring SF, Rossiter CD, Yates BJ (1997) Pressor response elicited by nose-up vestibular stimulation in cats. Exp Brain Res 113:165–168

Yates BJ (1992) Vestibular influences on the sympathetic nervous system. Brain Res Rev 17:51–59

Yates BJ, Miller AD (1994) Properties of sympathetic reflexes elicited by natural vestibular stimulation: implications for cardiovascular control. J Neurophysiol 71:2087–2092

Yates BJ, Aoki M, Burchill P, Bronstein AM, Gresty MA (1999) Cardiovascular responses elicited by linear acceleration in humans. Exp Brain Res 125:476–484

Yates BJ, Holmes MJ, Jian BJ (2000) Adaptive plasticity in vestibular influences on cardiovascular control. Brain Res Bull 53:3–9

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Damping control of balance in the medial/lateral direction and the risk of falling in the elderly

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Aims: A proportional–integral–derivative (PID) control has recently been used as a control algorithm of body balance. The purpose of this study was to elucidate an association of the proportional and derivative gain based on the PID control gain for balance for quiet standing with the risk factor for falls in the elderly.

Methods: The movement of a marker on the back of 23 elderly participants (age 75.6 ± 6.6 years) was measured by our developed device with a complementary metal oxide semiconductor video camera and the trunk sway speed in the medial/lateral (M/L) direction (*TSSX*) was calculated as absolute values of the whole time series. The PID control gain (proportional gain: K_P, integral gain: K_I, derivative gain: K_D) was identified using the trunk sway data, and normalized by individual height and weight (K_Pn, K_Dn and K_In). Individual risk factor for falls was additionally assessed with the Tinetti Performance Oriented Mobility Assessment (POMA) and the fall risk questionnaire.

Results: The score in the POMA and the K_Dn significantly decreased with age ($P < 0.01$). The score in the POMA showed a positive correlation with the K_Dn, and negative correlations with the *TSSX* and K_P/K_D ratios ($P < 0.01$). The average K_Dn and the score in the POMA of fallers were significantly lower than those of non-fallers ($P < 0.05$).

Conclusion: These results suggest that the decreased damping control by derivative gain for balance in the M/L direction is one of the risk factors for falls in the elderly. **Geriatr Gerontol Int 2013; 13: 182–189.**

Keywords: damping control, elderly, medial/lateral direction, risk of falling, trunk sway.

Introduction

Studies on the control of human upright stance in the direction of the anterior/posterior (A/P) are popular, because it is the direction of walking and falling;[1–3] however, recent reports have identified an association between falling and instability in the medial/lateral (M/L) direction.[4,5] Falling in a M/L direction often causes hip fractures, thus resulting in a reduced quality of life as a result of serious problems in standing and walking, as well as falling forward or backward, especially in the elderly.[6] Maki *et al.* recently reported that posturographic measurements in the M/L direction are the best predictors of risk of falling in the elderly. The parameters representing M/L postural control activity were most strongly associated with a history of falls and highly correlated with clinical risk factors for falling.[4,7] Chiba *et al.* also showed that increased lateral trunk sway during walking is one of the risk factors for falls in the elderly.[8]

Recent studies have shown the importance of velocity information, as well as position information, in controlling balance during quiet stance. In the central nervous system (CNS) control using position and velocity feedback, a proportional–integral–derivative (PID) control has been used as a working model of the body balance control algorithm.[2,9] In other words, the CNS detects the error signal and activates the selected muscles to generate the corrective torque to minimize the error for keeping upright. The PID controller simulating the regulation of postural balance carried out by the CNS was defined by the proportional: K_P, derivative: K_D and integral gains: K_I, respectively.[2]

The increasing stiffness that is controlled by proportional gain (K_P) alone induces larger overshoots and longer settling time to maintain an upright position, resulting in oscillatory behavior, whereas the increasing of damping controlled by derivative gain (K_D) reduces the magnitude of the oscillations with faster settling

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time to maintain an upright position. Swiftness, which is controlled by integral gain (K_I), can be used to reduce steady state error during the upright stance; however, its effect is thought to be much smaller than stiffness and damping.[9] The elderly are generally thought to be "stiffer," especially the elderly that have experienced a fall, who tend to show increased ankle stiffness in comparison with non-fallers.[10] Co-contraction is one mechanism for the elderly to increase stiffness when exposed to changes in sensory information.[11] This action might be a compensatory response to balance perturbation in the elderly to compensate for loss of sensory and motor function as a result of aging in rapid perturbation.

Decreased muscle strength associated with stiffness control has been thought to be an important risk factor for falls in the elderly. It has been reported that the advantage of muscle strength training is the reduction of the risk of falling.[12] However, muscle strength training alone is not sufficient to improve postural balance. The falls might be also highly correlated with balance disability as a result of loss of visual, vestibular and proprioceptive inputs, which are associated with the damping factor for postural control. Muscle strength training combined with balance training is therefore more effective to prevent falls in the elderly with loss of sensory and motor function as a result of aging.[13,14] However, how such training should be used by older adults with risk factors for falls is not yet fully understood.

The Tinetti Performance Oriented Mobility Assessment (POMA) is a widely used clinical measure for balance and gait of the elderly to determine the risk of falling within the next year. The reliability and validity of the POMA is well demonstrated.[15,16] However, the POMA has some disadvantages in clinical practice. First, it is relatively complicated to be implemented and hence is time-consuming. Second, this tool has difficulty in assessing subtle changes of training and treatment. Third, the score in the POMA does not always indicate therapeutic problems. The purpose of the present study was to elucidate the stiffness and damping control of balance in the M/L direction for quiet standing with our newly-developed system, and to test the benefit of the PID controller gain as a predictor of risk of falling in the elderly.

Methods

Participants

We recruited the participants from patients who visited Gifu University Hospital, and the present study included 23 older adults (9 males and 14 females) aged from 65 to 85 years (75.6 ± 6.6 years) without any pathology of musculoskeletal injuries or neurological disorders that impaired their ability to ambulate independently. The local Ethics Committee of Gifu University Graduate School of Medicine approved the present study. Written informed consent was obtained from all participants after a complete description of the study.

Device and procedure for trunk sway assessment

The participants in the present study wore a white vest with a 3-cm in diameter black circular marker attached on the back at the level of the fourth thoracic vertebrate. The participants were asked to keep standing with a 30-degree angle between the medial sides of the feet and a heel-to-heel separation of approximately 2 cm. The participants were told to look ahead at a 2-cm maker at eye level at a distance of 1.5 m. The marker attached to the participant's back was tracked by complementary metal oxide semiconductor camera, offering 1.3 million pixels (ARTCAM-130MI; ARTRAY, Tokyo, Japan) located 1.5 m behind the participants for 60 s, as previously described.[7] The capture resolution was set to 640 × 480 pixels; with 640 pixels in the x-direction. The image recognition and data processing were computerized with a recording speed of 15 frames per second (Fig. 1). The image of the marker was binarized with a differentiating histogram method, and the locus of the center of the image was recognized and recorded on the computer system. The scalar of the locus on real coordinates could be calculated by the number of pixels equivalent to the diameter of the marker. The average trunk sway speed (TSS) was calculated as the absolute values of the whole time series, and the altitude of the measurement point was standardized in order to assess the TSS between individuals, because the height of participants differed. Therefore, the trunk sway speed in the M/L direction (*TSSX*) was assessed to be the first difference divided by the time increment, which was adjusted at a level of 1.0 m height from the floor. The trunk sway in the M/L direction was selected, and all measurements were carried out only in an eyes-open state.

Model description in upright stance

An inverted pendulum model was used, which includes the structural characteristics of the pelvis connecting the vertebral column and the two lower limbs with the lumbosacral joint and hip joint respectively, based on the model described by Winter *et al.*[1] The distance between the feet was assumed to be equal to the distance between the two hip joints, and the ankle joints remained fixed in order to make the dynamics analysis concise. The origin was set at zero (half way between the ankle joints) and that the knees were locked. A participant sways to the right, and the vertical ground reaction force (R) has the center of pressure (COP) located a distance "p," and the bodyweight less the weight of the

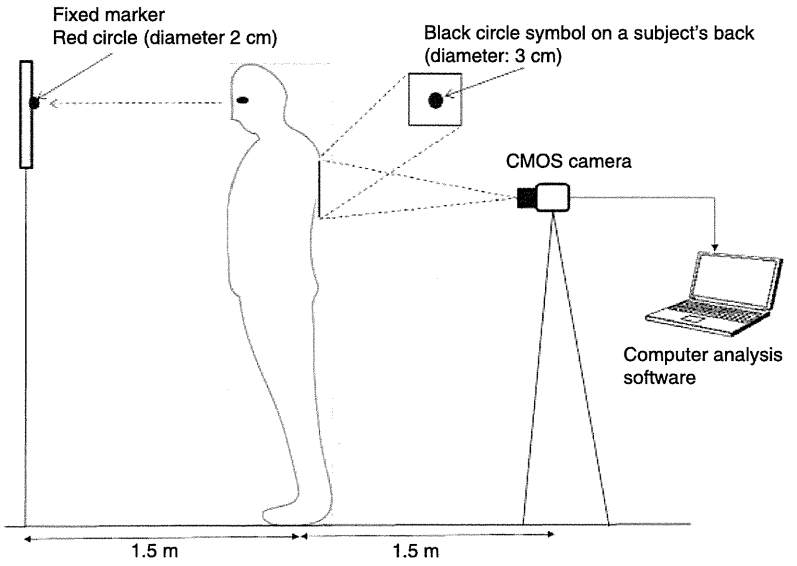

Figure 1 The computer system for measuring the trunk sway. The computer system is composed of a marker for image recognization, a complementary metal oxide semiconductor camera for image recording and a personal computer for data processing. A board with a red circle marker was set 1.5 m in front of the participant to act as a visual target at eye level.

feet (W) acts at a distance "x" from the origin (Fig. 2). The horizontal ankle reaction force is small (<1 N) in the quiet stance, and therefore it can be ignored.

The distance of the pendulum about the origin (x) in this model could be calculated using the equation below based on the trajectory of the marker on the back of the participant. Considering the center of gravity from the ankle to be located at a height of h (h was estimated from the height of the participant based on the standard ratio[17]), the sway angle of the pendulum about the origin in quiet stance (θ) can be calculated by the equation below because of the small angular sways. In addition, as the θ is very small,

$$\theta \approx -\frac{x}{h}$$

The center of mass (COM) in the quiet stance is displaced by one single moment of reacting force, which can be equal to the corrective torque to activate the ankle and hip (Tc) at the origin. In conclusion,

$$Tc = I\ddot{\theta} - mgh\theta \quad (1)$$

(I: the moment of inertia of the pendulum acting about the origin in this model, $\ddot{\theta}$: angular acceleration of the pendulum about the origin, m: body mass, g: the acceleration due to gravity)

PID control and simulation

The body dynamics and kinematics during quiet stance were described using an inverted pendulum model. The input to the body model was the corrective torque generated by the CNS in response to body motion and disturbance. A PID feedback control mechanism was proposed for the corrective torque generating process, and the PID controller was defined with the proportional, derivative and integral gain factors (K_P, K_D *and* K_I). The corrective torque was calculated as shown in the equation.

$$Tc(t) = K_P\theta(t-t_d) + K_D\dot{\theta}(t-t_d) + K_I\int_0^t \theta(t-t_d)dt \quad (2)$$

(t_d is the time delay; K_P, K_D and K_I are the gains of a PID control law)

Combining (1) and (2),

$$K_P\theta(t-t_d) + K_D\dot{\theta}(t-t_d) + K_I\int_0^t \theta(t-t_d)dt = I\ddot{\theta} - mgh\theta \quad (3)$$

The delay time (t_d) includes the sensory time delay, which represents the cumulative time loss as a result of neural transmission from the sensory system (proprioceptive, vestibular and visual systems) and the command time delay, which represents cumulative time loss as a result of the CNS decision-making process. Using the trunk sway data for PID gain estimation, it follows from the aforementioned equations that the scalar parameters K_P, K_D, K_I and t_d can be identified by observations of θ, and calculated by the least squares method. A major contribution to the overall noise in human postural control might stem from the sensory organs.[18] It might thus be plausible to add a noise source to the sensory signal. There are several kinds of noise that affect the sensory signal. However, the current model includes only one noise source, which was injected as a random disturbance torque obtained by the low-pass filtered Gaussian noise source.

The CNS detects the error signal, and activates the hip and ankle muscle to generate the corrective torque to minimize the error. Humans maintain their body

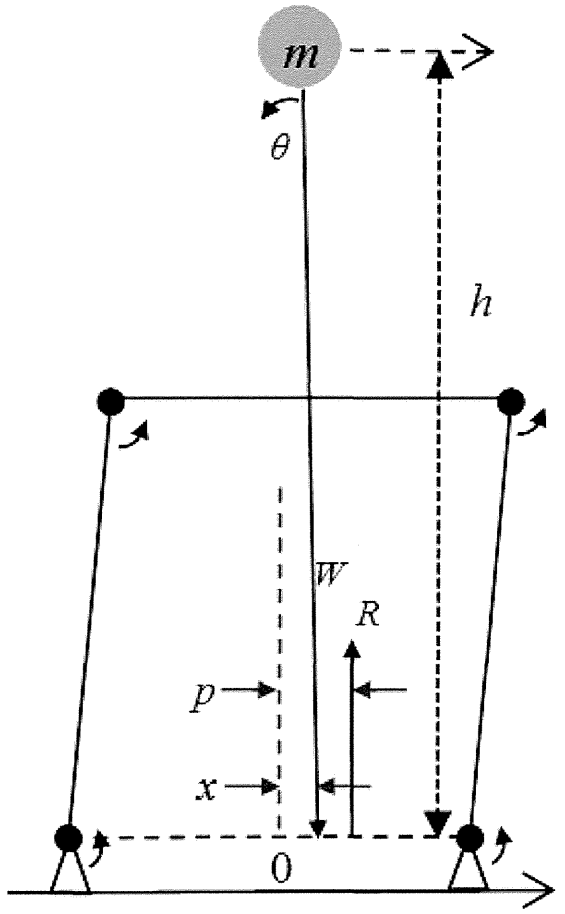

Figure 2 An inverted pendulum model in the frontal plane of upright stance. When a participant sways to the right, the vertical ground reaction force (*R*) has the center of pressure at distance "*p*" and the body mass acts at distance "*x*" from the origin 0. θ, Sway angle of the pendulum about the origin in quiet stance; *g*, gravitational acceleration; *h*, height from the ankle to the center of gravity of the whole body; *m*, body mass.

balance by adaptation of K_P, K_D and K_I. The neural controller properties are specified by the three constants K_P, K_D and K_I, which scale the components of the control torque, and are gain constants that determine the magnitude of the position, velocity and time integral of the angular deviation, respectively. The values of K_P, K_D and K_I were normalized as $K_Pn = K_P/mgh$, $K_Dn = K_D/mgh$ and $K_In = K_I/mgh$, where m is body mass, g is the acceleration due to gravity, and h is height from the ankle to the center of gravity of the whole body, because PID control parameters are affected by bodyweight and height.

Tinetti Performance Oriented Mobility Assessment

The total POMA scale (POMA-T) consists of a balance scale (POMA-B) and a gait scale (POMA-G). First, each participant was invited to carry out the eight manoeuvres (sitting balance, rising up from a chair, immediate and prolonged standing balance, withstanding a nudge on the sternum, balance with eyes closed, turning balance and sitting down) of the POMA-B, as described in the original protocol.[15] Second, each participant was invited to walk, turn and walk back without a walking aid (initiation, step length and height, step continuity, symmetry, path deviation, trunk sway, walking stance and turning while walking), as described in the original protocol.[15] The POMA was scored based on either a three-point scale (0–2) or two-point scale (0–1) representing the most impairment, with lower scores indicating increased fall risk. The participants with a total score of <25 in the POMA-T might be at risk for experiencing falls.[15]

Fall risk questionnaire

The questionnaire, including some item self-assessments designed to identify common risk factors for falls, was carried out in all participants of the present study. The difference in POMA-T, *TSSX* and PID parameters were analyzed between two groups classified based on the answers to following questions: (i) "Have you had a fall in the past year?"; (ii) "Have you had a near fall in the past year?"; (iii) "Do you have a fear of falling that restricts your activity?" and (iv) "Do you take five or more prescription medication daily?".

Statistical analysis

The correlations between the score in the POMA-T and PID control parameters were analyzed with Spearman's correlation test. Non-parametric Mann–Whitney *U*-test was carried out on the parameters of the aforementioned examinations among groups because of unequal variances of the data among groups and the small number of patients in the present study. The level of significance of the two-tailed $P < 0.05$ was used throughout the study. The data in this text represent the average ± 1 standard deviation of multiple measurements.

Results

The average score in the POMA-T, POMA-B and POMA-G were 25.6 ± 3.5 (range 17–28), 15.0 ± 1.9 (range 8–16) and 10.5 ± 2.0 (range 5–12), respectively. The average *TSSX* was 3.98 ± 1.62 mm/s, which was significantly higher than that of a young age group observed in a previous study (2.77 ± 0.43 mm/s). The PID controller gains of K_Pn, K_Dn and K_In were 0.046 ± 0.005, 0.005 ± 0.002 and 0.00016 ± 0.00017, respectively. The average K_P/K_D ratio, which represents the dependency for stiffness or damping to remain upright, was 9.9 ± 3.7.

The score in the POMA-T and the K_Dn significantly decreased with age ($r = -0.8$ and $r = -0.63$, $P < 0.01$; Fig. 3). There was a significant correlation between K_P/K_D ratio and age ($r = 0.59$, $P < 0.01$). The *TSSX* tended to increase with age ($r = 0.4$, $P = 0.06$); however, K_Pn and K_In never correlated with age ($P > 0.05$). The *TSSX* negatively correlated with the K_Dn ($r = -0.48$, $P < 0.05$); however, there was no correlation of the *TSSX* with K_Pn and K_In ($P > 0.05$). The score in the POMA-T was significantly negatively correlated with the *TSSX* ($r = -0.53$, $P < 0.01$) and K_P/K_D ratios (–0.53, $P < 0.01$), and the score in the POMA-T positively correlated with the K_Dn ($r = 0.62$, $P < 0.01$; Fig. 4). The score in the POMA-T was never correlated with the K_Pn ($r = 0.06$, $P > 0.05$) or K_In ($r = -0.12$, $P > 0.05$).

Differences in collected parameters between the participants aged over 75 years and less than 75 years were analyzed, because all participants aged less than 75 years had a full score in the POMA-T and participants aged over 75 years had significantly lower scores in the POMA-T. The average *TSSX* in participants aged over 75 years was 3.9 ± 1.8 mm/s, which was not different from that in participants aged less than 75 years (4.1 ± 1.7 mm/s, $P > 0.05$). There was no significant difference in K_Pn, K_Dn and K_In between both groups ($P > 0.05$).

The participants in the present study consisted of four fallers and 19 non-fallers. There was no significant difference in average age between both groups (fallers 79.5 ± 2.4 years, non-fallers 74.2 ± 6.8 years). The scores in the POMA-T and K_Dn (21.3 ± 3.1 and 0.003 ± 0.001) of fallers were significantly lower than non-fallers (26.8 ± 2.1 and 0.006 ± 0.002, $P < 0.05$; Fig. 5). The K_P/K_D ratios of the fallers (13.2 ± 4.2) was significantly higher than that of non-fallers (8.7 ± 2.2, $P < 0.01$). However, there was no significant difference in *TSSX*, K_Pn and K_In between both groups ($P > 0.05$).

The elderly who took five or more prescription medications daily ($n = 5$) had significantly lower K_Dn (0.003 ± 0.001) and lower scores in the POMA-T (22.6 ± 4.0) than the elderly who took four or fewer prescription medications daily ($n = 18$, 0.006 ± 0.002 and 26.7 ± 2.1, respectively; $P < 0.05$). The elderly with a fear of falling ($n = 4$) had significantly higher *TSSX* (5.7 ± 1.8 mm/s), lower K_Dn (0.003 ± 0.001) and lower score in the POMA-T (22.0 ± 3.9) than the elderly without a fear of falling ($n = 19$, 3.6 ± 1.4, 0.006 ± 0.002 and 26.7 ± 2.1, respectively; $P < 0.05$). The *TSSX*, K_Pn, K_Dn, K_In and POMA-T in the elderly with a near fall ($n = 10$) were not significantly different from those in the elderly without a near fall ($n = 13$, $P > 0.05$).

Discussion

Previous studies emphasized the importance of the body velocity information to remain upright in the control system.[9,18,19] A simple PID control as the feedback

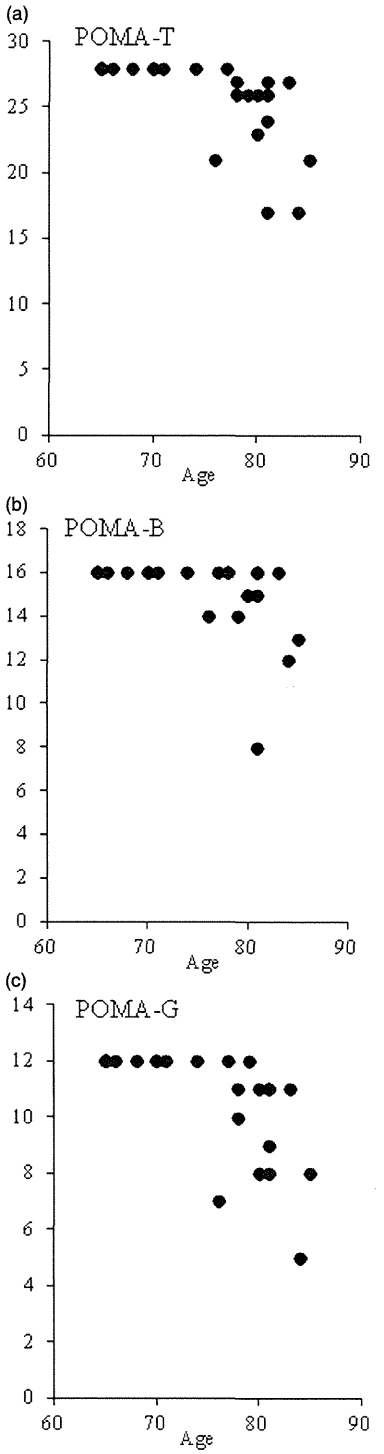

Figure 3 The correlation of age with the total Tinetti Performance Oriented Mobility Assessment (POMA-T), balance scale (POMA-B) and gait scale (POMA-G) in all participants. All correlations were significant at $P < 0.01$.

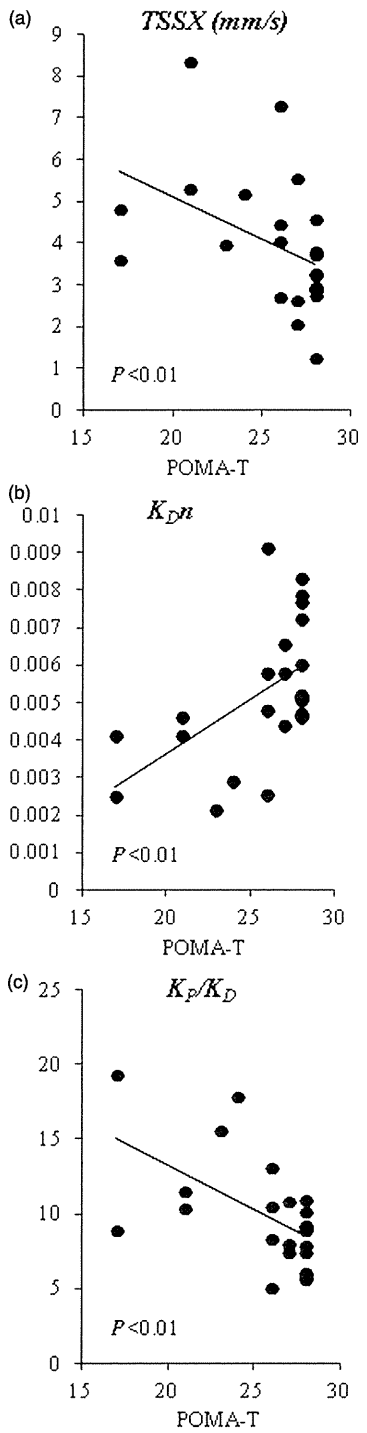

Figure 4 The correlation of the total Tinetti Performance Oriented Mobility Assessment (POMA-T) with (a) the trunk sway speed in the M/L direction (*TSSX*), (b) normalized derivative gain (K_Dn) and (c) proportional gain/derivative gain (K_P/K_D) ratio. All correlations were significant at $P < 0.01$.

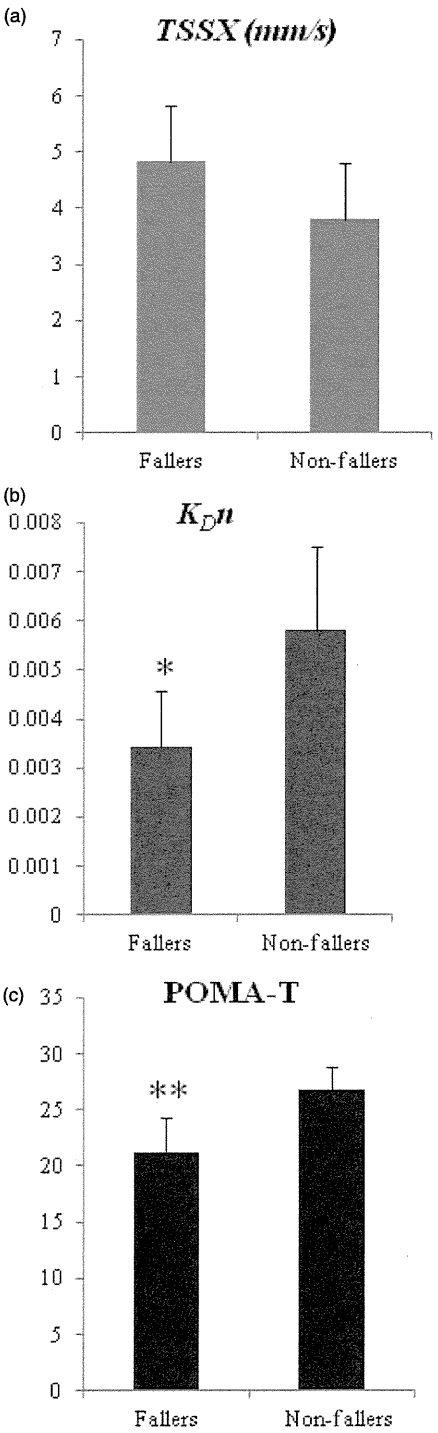

Figure 5 Differences in (a) the trunk sway speed in the M/L direction (*TSSX*), (b) normalized derivative gain (K_Dn) and (c) the total Tinetti Performance Oriented Mobility Assessment (POMA-T) between fallers and non-fallers. $^*P < 0.05$, $^{**}P < 0.01$ significant difference from non-fallers.

mechanism regulated by the CNS with control strategy based on the velocity information in an inverted pendulum model has been reported.[3,20,21] Some studies have shown that the elderly highly depend on the ankle joint muscle mass to enhance the ankle stiffness during quiet stance in comparison with young adults. The decrease of the muscle mass induces disability of body balance, resulting in increasing the risk for falls.[10] However, the value of K_Pn, which is the proportional gain to control the stiffness, did not increase with age in the present study, possibly because the results in the present study were analyzed with only data of the elderly aged more than 65 year. However, previous studies have shown that dependency on the stiffness for maintaining postural balance increases with age.[1,11] Masani *et al.* showed that the K_P/K_D ratio of the PID controllers in young adults was in the range of 1.00–5.57.[20] The K_P/K_D ratio of the elderly in the present study was 5.1–19.3, which was much higher than the ratio of young adults in the study by Masani *et al.* In addition, the K_P/K_D ratio significantly increased with age, and the ratio in fallers was significantly higher than that in non-fallers in the present study. The recurrent results suggest that an increase in the dependence on stiffness control and a decrease of the damping control with age for postural control might thereby induce disability of repositioning to stably upright, resulting in that the elderly are prone to fall by unexpected external perturbation.[22]

The integration of multisensory information to obtain position and velocity information of the body sway at the CNS is necessary to stabilize the body.[23] Several studies have suggested that proprioceptive information plays a significant role in the velocity feedback mechanism for the control of quiet stance.[9,20] Age-related deterioration of sensory and neuromuscular control mechanisms might also be responsible for the greater muscle activity of the elderly. Such changes could occur in the elderly under conditions of decreased muscle strength or with a decline in nerve conduction speed, both of which have been shown to occur with age.[24] A significant correlation between the *TSSX* and the K_Dn in the present study might show that the importance of the body velocity information in the control system for quiet standing in the elderly. The K_Dn also significantly decreased with age and positively correlated with the score in the POMA-T in the present study. The present results therefore suggest that the velocity feedback mechanism for control of quiet stance is diminished with age, and that the elderly who have a decrease of the derivative gain for quiet standing are at increased risk for falls. We believe that our system can be a simple and convenient device to quantify the control strategy of the CNS in order to predict the risk of falling.

It has been reported that the advantage of muscle strength training is the reduction of the risk of falling.[12] However, there was no correlation between the score in the POMA-T and the value of K_Pn, which is the proportional gain to control the stiffness that is associated with muscle strength. A recent study reported that enhanced balance training can improve mobility of the elderly with balance problems.[25] The present results might show that balance training might be more efficient than muscle strength training alone to prevent older adults with decreased damping control for quiet standing from falling.

The elderly are prone to depending on the information of position parameters for postural control, although the CNS in young adults uses a control strategy that relies considerably on the velocity information in the control system of quiet standing.[19] The CNS therefore controls some muscles to stay upright using position and velocity feedback as the proportional–derivative (PD) control, which is used to approximate the control process that enables standing, and this model provides valuable insights into balance-related phenomena, such as body sway and falling.[20,21] The real system for postural control using the neural control system in humans is not as simple as the feedback system of the PID controllers. In fact, the integral component (K_I) as the PID controller acts to attenuate the oscillation of body sway. However, the K_I has been ignored, because the value of K_I is much lower than the value of the other controller gains (K_P and K_D), as also observed in the present study. In addition, a recent paper reported that quiet standing also requires cognitive resources that can be influenced by aging.[26] An evaluation of the cognitive resources for the postural control in the elderly might be required to evaluate the mechanism of postural control in the elderly precisely.

The POMA-T score significantly decreased with age, and correlated with K_Dn and K_P/K_D ratio in the present study. The POMA is designed to determine the risk of falling within the next years for the elderly.[6] There was no significant difference in *TSSX* and K_Pn between fallers and non-fallers; however, fallers showed a significantly lower K_Dn and lower score in the POMA-T than non-fallers in the present study. Similar results were found in the elderly with a fear of falling and the elderly who took five or more prescription medications daily. The current results suggest that the feedback mechanism based on body velocity information positively contributes to the prevention of falling in the elderly, and that the K_Dn of the PID controller to remain upright in the M/L direction could be the best predictor of risk of falling in the elderly. The PID control model has been used to approximate the control process that enables standing, and this model can give us valuable insights into the fall-prevention strategy in the elderly with risk factors for falls by assessing the stiffness and damping factor in the feedback system for postural control. Further studies will be required to confirm the present results, because the present study has a few

limitations, including the fact that the number of participants was small and it is necessary to evaluate what physiological mechanisms are equivalent to neural control in this model. However, further application of this system for the assessment of fall prevention might be helpful to elucidate the multiple mechanisms responsible for postural control in the elderly.

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Disclosure statement

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

References

1 Winter DA, Patla AE, Prince F, Ishac M, Gielo-Perczak K. Stiffness control of balance in quiet standing. *J Neurophysiol* 1998; **80**: 1211–1221.
2 Peterka RJ. Sensorimotor integration in human postural control. *J Neurophysiol* 2002; **88**: 1097–1118.
3 Maurer C, Peterka RJ. A new interpretation of spontaneous sway measures based on a simple model of human postural control. *J Neurophysiol* 2005; **93**: 189–200.
4 Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol* 1994; **49**: M72–M84.
5 Mitchell SL, Collins JJ, De Luca CJ, Burrows A, Lipsitz LA. Open-loop and closed-loop postural control mechanisms in Parkinson's disease: increased mediolateral activity during quiet standing. *Neurosci Lett* 1995; **197**: 133–136.
6 Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988; **319**: 1701–1707.
7 Nishihori T, Aoki M, Jian Y, Nagasaki S, Furuta Y, Ito Y. Effects of aging on lateral stability in quiet stance. *Aging Clin Exp Res* 2011. doi: 10.3275/7626.
8 Chiba H, Ebihara S, Tomita N, Sasaki H, Butler JP. Differential gait kinematics between fallers and non-fallers in community-dwelling elderly people. *Geriatr Gerontol Int* 2005; **5**: 127–134.
9 Morasso PG, Sanguineti V. Ankle muscle stiffness alone cannot stabilize balance during quiet standing. *J Neurophysiol* 2002; **88**: 2157–2162.
10 Allum JH, Carpenter MG, Honegger F, Adkin AL, Bloem BR. Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. *J Physiol* 2002; **542**: 643–663.
11 Benjuya N, Melzer I, Kaplanski J. Aging-induced shifts from a reliance on sensory input to muscle cocontraction during balanced standing. *J Gerontol A Biol Sci Med Sci* 2004; **59**: 166–171.
12 Orr R. Contribution of muscle weakness to postural instability in the elderly A systematic review. *Eur J Phys Rehabil Med* 2010; **46**: 183–220.
13 Horlings CG, van Engelen BG, Allum JH, Bloem BR. A weak balance: the contribution of muscle weakness to postural instability and falls. *Nat Clin Pract Neurol* 2008; **4**: 504–515.
14 Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiol (Oxf)* 2008; **193**: 101–116.
15 Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986; **34**: 119–126.
16 Tinetti ME, Liu WL, Claus EB. Predictors and prognosis of inability to get up after falls among elderly persons. *JAMA* 1993; **269**: 65–70.
17 Winter DA, Patla AE, Frank JS. Assessment of balance control in humans. *Med Prog Technol* 1990; **16**: 31–51.
18 van der Kooij H, Jacobs R, Koopman B, van der Helm F. An adaptive model of sensory integration in a dynamic environment applied to human stance control. *Biol Cybern* 2001; **84**: 103–115.
19 Jeka J, Oie K, Schoner G, Dijkstra T, Henson E. Position and velocity coupling of postural sway to somatosensory drive. *J Neurophysiol* 1998; **79**: 1661–1674.
20 Masani K, Popovic MR, Nakazawa K, Kouzaki M, Nozaki D. Importance of body sway velocity information in controlling ankle extensor activities during quiet stance. *J Neurophysiol* 2003; **90**: 3774–3782.
21 Peterka RJ. Postural control model interpretation of stabilogram diffusion analysis. *Biol Cybern* 2000; **82**: 335–343.
22 Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age Ageing* 2006; **35** (Suppl 2): ii7–ii11.
23 Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configurations. *J Neurophysiol* 1986; **55**: 1369–1381.
24 Hurley MV, Rees J, Newham DJ. Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects. *Age Ageing* 1998; **27**: 55–62.
25 Steadman J, Donaldson N, Kalra L. A randomized controlled trial of an enhanced balance training program to improve mobility and reduce falls in elderly patients. *J Am Geriatr Soc* 2003; **51**: 847–852.
26 Lacour M, Bernard-Demanze L, Dumitrescu M. Posture control, aging, and attention resources: models and posture-analysis methods. *Neurophysiol Clin* 2008; **38**: 411–421.

Review

Management of chronic dizziness

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Abstract

The main pathology of dizziness is unilateral vestibular dysfunction and it usually disappears in a few days after the reappearance of resting neural activity in the ipsilateral vestibular nuclei and the rebalancing of the bilateral vestibular nuclei. However, some patients suffer from chronic dizziness because of a failure of compensation, which may be due to maladaptive behavior, psychological disorders, and impairment of other sensory inputs or the chronic use of drugs acting on the central nervous system. Patients with chronic dizziness often show autonomic dysfunction and psychological disorder caused by the distress arising from inappropriate treatment for vestibular dysfunction. In addition, chronic dizziness caused by bilateral vestibular dysfunction and central vestibular disorder is generally intractable. An approach is therefore needed which addresses the various aspects of chronic dizziness in order to achieve a cure.

Keywords: dizziness; compensation; vestibular exercise.

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Introduction

Dizziness is an extremely common complaint of patients visiting primary care centers. The pathological processes underlying the development of dizziness vary widely, and patients consult with many different specialists, but mainly visit the otolaryngology or neurology departments. The most common pathology of dizziness is unilateral vestibular dysfunction, which leads to severe symptoms including vertigo and a tendency to veer or fall to the affected side. The accompanying clinical signs are spontaneous nystagmus, roll and yaw head tilt and postural unsteadiness due to contralateral limb extension and ipsilateral limb flexion [1-3]. More rarely, the patient may complain of transient vertical diplopia and ipsiversive cyclotorsion of the eyes and a skew of the lower eye to the lesioned side. These signs are related to the differences in the levels of tonic activity in the central vestibular nuclei due to peripheral vestibular disorders. Spontaneous nystagmus including static oculomotor dysfunction generally recovers in two or three hours after the onset of the lesion and disappears in a few days after the reappearance of resting neural activity in the ipsilateral vestibular nuclei and the rebalancing of the bilateral vestibular nuclei. Unilateral vestibular loss causes a vestibular perception of an erroneous tilt of the body, which is enhanced when rapid perturbations of posture make somatosensory cues difficult to interpret [4].

However, it may take more than a month for the central nervous system (CNS) to adapt to the new input during head motion [5]. Some patients complain of chronic dizziness and transient vertigo provoked by certain environment or activities. The former complaint shows incomplete resolution of symptoms with persistent failure of recovery from the initial insult to the vestibular system, while the latter complaint demonstrates that it is usually a subclinical disorder, but they suffer from recurrent episodes. There may be single or multiple reasons for the failure of compensation [6]. First, they may have fluctuating function in the peripheral or central vestibular system (e.g. Meniere's disease, autoimmune or hereditary vestibular disorder, recurrent benign paroxysmal positional vertigo; BPPV). Second, they may be confined to maladaptive behavior because they avoid the intermittent symptoms associated with head movements due to vestibular disorders, resulting in delay in the vestibular compensation process. Third, psychological disorders such as preexisting or secondary anxiety and panic disorders may interfere with the compensation process. Fourth, they may have impairment of other sensory inputs (vision and proprioception) which are required for balance recovery (e.g. low vision, cataract, macular degeneration, and peripheral neuropathy due to diabetes and collagen disease). Finally, the chronic use of drugs acting on the CNS delays the compensation process (vestibular suppressant drugs, meclizine, antihistamine, anticholinergic agents and benzodiazepines).

It is important to distinguish these symptoms from ongoing altered and fluctuating functions of the inner ear itself. Most patients have episodes of decompensation in response to new physical or emotional stresses. It is helpful to distinguish central decompensation from a recurrence of the original ear problem for the successful treatment of chronic dizziness. This paper reviews the pathology and management of chronic dizziness.

Interview for Chronic Dizziness

It is important to understand the clinical course and feature of the dizziness based on the patients' experiences. The symptoms associated with dizziness during the acute phase may be a clue to making the correct diagnosis. Physicians should distinguish general unsteadiness from a rotational sensation. Vertigo usually indicates vestibular disease and a sensation of tilting or falling may also be provoked by vestibular disease. However, an inappropriate treatment for a long period can affect the nervous system, resulting in weakness, which decreases the everyday activities. Therefore, the complaints of patients may include not only vertigo and dizziness, but also disequilibrium, lightheadedness, a floating sensation, fatigue, poor concentration, disorientation, visual disturbances, oscillopsia, headaches, anxiety and panic disorders, muscle tension, depression, poor coordination, noise sensitivity, motion sickness, ear pain and hypersensitivity to light, pressure or temperature changes.

The patient's disease history, employment history, lifestyle, stress status and regularity of the menstrual cycle, as well as medications being taken for other disease, (e.g. anti-hypertension, tranquilizers, antidepressants) are usually required for the differential diagnosis of dizziness. It is helpful to obtain an account of the patient's perception of their illness and the degree of functional daily disability arising due to the presence of vestibular disorder.

Table 1. Causes/diagnoses of chronic dizziness

Otological Positional vertigo (BPPV), Labyrinthitis, Vestibular neuronitis, Head & neck trauma, Meniere's disease, Sudden deafness with vertigo, Ototoxicity, Superior semicircular canal dehiscence syndrome, Paget's disease Perilymphatic fistula, Mal de debarquement, Enlarged vestibular aqueduct
Neurological Migraine-related vertigo, Acoustic neuroma, Multiple sclerosis, Ischemic brain change, Vertebral artery occlusion, MLF syndrome, Parinaud's syndrome, Spinocerebellar degeneration, Superficial siderosis, Chronic subdural hematoma, Spontaneous intracranial hypotension, Wernicke's encephalopathy, Presbyastasis, Opsoclonus-polymyoclonus syndrome, Chiari malformation,
General Orthostatic hypotension, Postural orthostatic tachycardia syndrome, Inappropriate sinus tachycardia, Anemia, Hyperventilation, Hypoglycemia, Adams-Strokes syndrome, Asymmetry eye acuity, Cervicogenic dizziness, Panic disorder, anxiety, depression

Evaluation for Chronic Dizziness

Vestibular Examination

The successful management of patients with chronic dizziness requires an accurate diagnosis, assessment of the vestibular and neurologic impairment and an understanding of the degree of disability due to dizziness. Abnormal eye movement and nystagmus are important signs to diagnose the pathology of dizziness. When physicians test for gaze evoked nystagmus, it is necessary to check whether the patient has a gaze paresis. In right MLF syndrome, the patient will "see double" when looking to the left, however the convergence is generally preserved [7]. Parinaud's syndrome shows abnormalities of eye movement and pupil dysfunction with paralysis of the upgaze [8]. In addition, the examination should be thorough so that abnormal eye movements such as flutter-like oscillation, square wave jerks and opsoclonus-polymyoclonus are not missed.

Frenzel goggles are extremely useful for evaluating patients with vestibular disorders. Nystagmus can easily be seen, because fixation is removed and the eyes are magnified in a dark room. Recently, infra-red CCD Fenzel goggles have been recognized as a powerful tool for use in place of the classical Frenzel glasses.

The Dix-Hallpike maneuver is essential for confirming a diagnosis of BPPV [9]. The doll's eye reflex is an efficient test to detect vestibular disorders. The caloric reflex test is a test of the vestibulo-ocular reflex that involves irrigating the external auditory canal with cold or warm water or air [10]. The strength of this test is that it can be used to detect a disorder of the right and left semicircular canal separately for vestibular neuronitis, Meniere's disease and other types of inner ear dysfunction. If patients have a perilymphatic fistula, which is an abnormal connection between the air-filled middle ear and the fluid-filled inner ear, a compression of the air into the auditory canal induces nystagmus to the opposite side, and rarefaction induces a reverse nystagmus accompanying the dizziness. The functions of otolith organs may be detected by the subjective visual or postural vertical test and the vestibular evoked myogenic potential [4,11,12].

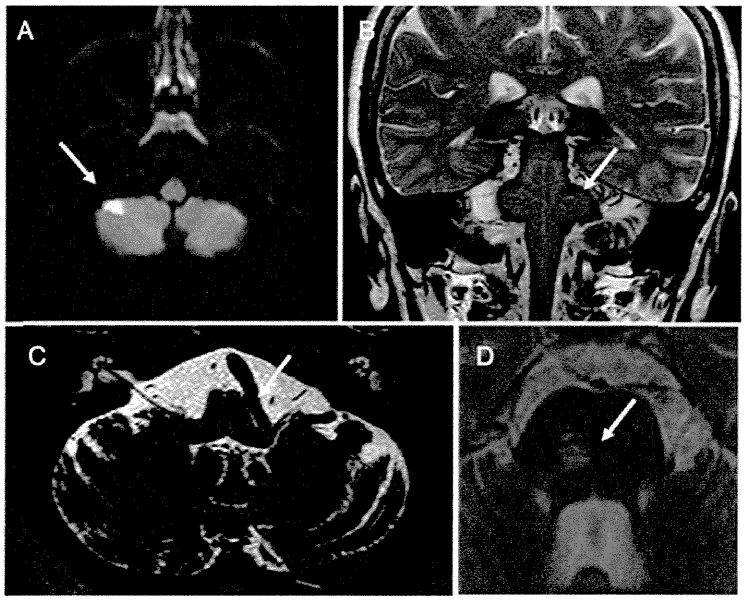

Figure 1. MRI findings of patients with chronic dizziness. A: AICA syndrome in a 64 year-old female with a history of paroxysmal atrial fibrillation, B: Superficial siderosis in a 60 year-old female, C: Dolichoectasia of the vertebrobasilar artery in a 49 year-old male, D: Pontine infarction in a 65 year-old man with a history of hypertension. The arrows show lesioned areas.

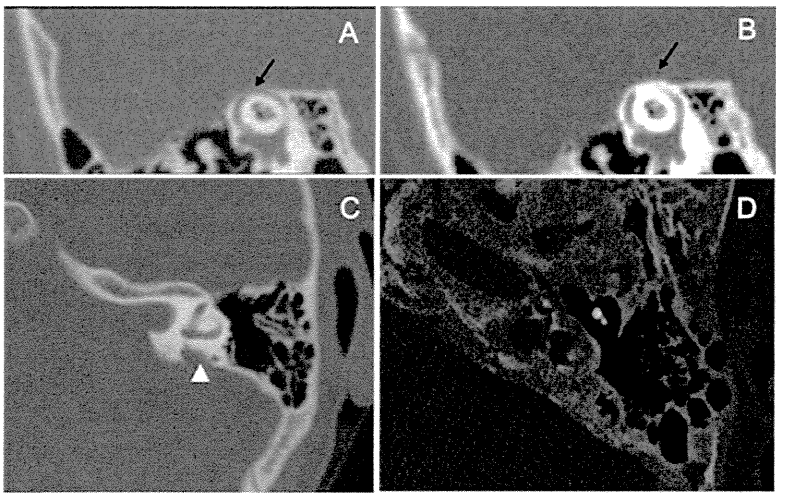

Figure 2. CT findings of a 30 year-old male with superior semicircular canal dehiscence before (A) and after (B) re-pair of the roof with bone cement. C: Enlarged vestibular aqueducts in a 15 year-old male, D: Paget's disease in 70 year-old male. The arrows show the roof of the superior semicircular canal (A, B) and the arrow head shows the en-larged vestibular aqueduct (C).

General Examination

Chronic dizziness occurs as a comorbid condition with the systemic conditions such as hyperlipidemia, diabetes, hypertension, autoimmune disorders and ophthalmological diseases. Orthopedic examination helps in the diagnosis of cervicogenic dizziness. An appropriate treatment should be selected, because systemic conditions may affect the vestibular compensation.

Complaints and physical findings in patients suffering from chronic dizziness frequently vary, and it is therefore important to assess how much their dizziness affects their daily lives by using questionnaires such as the dizziness handicap inventory (DHI). The DHI assesses precipitating physical factors associated with dizziness/unsteadiness and the functional/emotional consequences of symptoms as a measure of disability in patients with dizziness and unsteadiness [13].

Presbyastasis is the result of age-related physiological changes in the three sensory systems (visual, vestibular and somatosensory) and their central connections that help to maintain balance. Presbyastasis is therefore a complex condition involving many inter-related systems, rather than a single lesion within the vestibular system only, so the evaluation need to be holistic [14].

Patients with chronic dizziness frequently may show autonomic dysfunction and psychological disorders caused by distress arising due to an inappropriate treatment for vestibular dysfunction. Therefore, autonomic testing and psychological approaches may help to obtain the correct diagnosis.

The orthostatic test should be routinely used for patients with dizziness, especially the elderly patients, because the elderly dizzy patients are often diagnosed as symptomatic or asymptomatic orthostatic hypotension and the poor control of blood pressure can be a cause of chronic dizziness [15]. Stokes-Adams syndrome is rarely caused by sick sinus syndrome or severe reflex bradycardia, with asystole causing recurrent vertigo, chronic dizziness and syncope. If the arrhythmia is not immediately detected on the electrocardiogram (ECG), 24-hour Holter ECG monitoring may be helpful [16].

Many studies have reported an association between the vestibular dysfunction and psychological pathologies, such as agoraphobia, anxiety, panic disorder and depression. Psychological disturbance should be assessed because the recovery of vestibular function may be impossible and vestibular compensation may not be completed until the psychological factors have been appropriately managed [17].

Imaging Examination

Brain MRI is an important diagnostic aid for acoustic neuroma, multiple sclerosis, ischemic brain changes, chronic subdural hematoma, the Chiari malformation, spontaneous intracranial hypotension, dolichoectasia of the vertebrobasilar artery, and superficial siderosis (**Figure 1**). Most patients with chronic dizziness have normal findings on brain MRI, however cerebral white matter lesions (WMLs) and lacuna infarction are frequently found, especially in the elderly with chronic dizziness. Special attention should be paid to the WMLs, because they may be strongly associated with the development of stroke and dementia in the future [18].

CT scanning can detect superior canal dehiscence, perilymphatic fistulas due to cholesteatoma, enlarged vestibular aqueducts and the Mondini anomaly. The paget's disease is a chronic osteodystrophy of unknown etiology and its CT scanning shows demineralized temporal bone producing deafness and vertigo [19] (**Figure 2**).

Furthermore by confirming that there is no abnormal finding on their brain MRI, some patients can obtain reassurance and reduction of their anxiety about the dizziness possibly being due to a brain tumor or cerebral infarction.

Treatment for Chronic Dizziness

Surgical Treatment

Dizziness due to traumatic or idiopathic perilymphatic fistula and canal bone erosion due to cholesteatoma in the semicircular canal can be cured by surgical treatments. Patients with superior semicircular canal dehiscence syndrome (SCDS) can experience vertigo and oscillopsia evoked by loud noises and/or by maneuvers that change the middle-ear or intracranial pressure (such as coughing, sneezing, or straining). High-resolution CT scans of the temporal bones demonstrate an opening in the bone that should cover the superior semicircular canal. SCDS can also be surgically treated by repairing the dehiscence (**Figure 2**) [20]. Hearing loss or balance symptoms associated with an enlarged vestibular aqueduct (EVA) can occur when the endolymphatic duct and sac expand to fill

the larger space. Surgical obliteration of the endolymphatic sac may be helpful for patients with EVA suffering from recurrent vertigo [21]. Spontaneous intracranial hypotension (SIH) is caused by spontaneous spinal cerebrospinal fluid leaks and is known to cause orthostatic headaches and chronic dizziness. Epidural blood patch therapy has been selected for patients with SIH [22].

Conservative and Preventive Medicine

Migraine related-vertigo can be controlled by specific drugs. During an attack, triptans is efficient and other beta blocker, calcium antagonists have been used as prophylactic drug. Patients suffering from migraines should watch their diet, and avoid consuming tyramine such as that present in cheese, chocolate or red wine. The vestibular symptoms associated with migraines are very similar to those of Meniere's disease and they are frequently misdiagnosed as Meniere's disease [23]. Patients with Meniere's disease are recommended to implement salt restriction and diuretics, resulting in orthostatic intolerance and orthostatic hypotension due to dehydration. Conversely, patients with orthostatic hypotension should consume salt and water to relief their symptoms. Patients with migraine, Meniere's disease or hypotension are prone to suffer from motions sickness. The non-pharmacologic interventions to treat or manage motion sickness are the following: driving a vehicle instead of riding in it, sitting in the front seat of a car or bus, and drinking caffeinated beverages, along with mint and ginger [24].

Patients with Meniere's disease are usually treated with betahistine and central sedative drugs with vestibulo-suppressive or anti-emetic effect, and diuretic drugs are effective in some cases. Control of stress is essential to obtain a good prognosis, because patients suffering from intractable Meniere's disease show high concentrations of stress-related hormones such as prolactin, vasopressin and cortisol [25, 26]. A tympanostomy tube may be effective for certain cases of Meniere's disease and Meniette device delivering micropressure is a safe and minimally invasive treatment for the intractable vertigo symptoms of Meniere's disease [27]. Endolymphatic sac surgery has also been performed, however the clinical efficiency of such surgical treatment has been controversial. Intratympanic injection of gentamicin has been shown to be effective for intractable Meniere's disease, however, there is a risk of deafness developing in the treated ear [28]. If elderly patients with Meniere's disease undergo destructive surgery, they may suffer from chronic disequilibrium because of severe unilateral vestibular dysfunction. The use of destructive surgery or medical treatment using gentamicin must be carefully considered, because it has been reported that about 50% of Meniere's diseases will progress to become bilateral [29].

Mal de debarquement is the persistent sensation of swaying and imbalance following long travelling on ships and airplanes and it usually declines over time. However, the duration of the condition may continue for years in certain patients. Vestibular suppressants may be ineffective, but benzodiazepines can relieve the symptoms [30].

Chronic dizziness is often induced by autonomic or cardiovascular diseases including essential orthostatic hypotension (OH), neural mediated reflex syncope, multiple system atrophy, chronic heart failure, dehydration, postural tachycardia syndrome (POTS), inappropriate sinus tachycardia (IST) and, chronic fatigue syndrome. OH is defined by the American Autonomic Society as a systolic blood pressure decrease of at least 20 mm Hg or a diastolic blood pressure decrease of at least 10 mm Hg within three minutes of standing up [15]. POTS includes symptoms of orthostatic intolerance associated with an increase in heart rate from the supine to upright position of more than 30 beats per minute or to a heart rate greater than 120 beats per minute after standing up [31]. Patients with IST usually have average daily heart rates in excess of 100 beats per minute, and sinus tachycardia is always present. Therefore, the possible causes of IST, such as anemia, hyperthyroidism, volume depletion, fever, anxiety disorders, medications and cardiomyopathy must first be ruled out one by one [32].

Patients with orthostatic intolerance and dizziness should be encouraged to make slow, dorsiflex foot movements several times before standing, eat small, frequent meals, consume adequate salt, increase their fluid intake, elevate the head of their bed and wear compression stockings, all of which can help maintain blood volume. Patients should be also instructed to avoid standing motionless, alcohol, hot baths and dehydration, which provoke orthostatic dizziness. The use of vasopressors like midodorine, clonidine and beta-blockers can also relieve the orthostatic symptoms [33].

Empirical Therapy

Vertical nystagmus often aids in the diagnosis of central vestibular disorders. The compression of the caudal brainstem by dolichoectasia of the vertebrobasilar artery has now been included in downbeat nystagmus. Although Wernicke's encephalopathy is a fairly common diagnosis, and is associated with downbeat nystagmus induced by vitamin B-1 deficiency due to alcoholism or hyperemesis gravidarum, it is often missed or delayed in patients with chronic dizziness and disequilibrium. A Chiari malformation is a congenital defect in the area of the back of the head where the brain and spinal cord connect and often result in downbeat nystagmus and dizziness. The treatment for these diseases is empirical, however drugs including clonazepam, gabapentin, baclofen and carbamazepine may diminish the nystagmus and relieve the chronic dizziness [34].

Superficial siderosis is associated with sensorineural hearing loss, cerebellar ataxia and the pyramidal sign and the diagnosis can be made with the MRI-T2 image representing an extensive hemosiderin deposits superficially around brainstem and cerebellum (**Figure 2**). However, there is currently no cure for superficial siderosis, only treatments to help alleviate the symptoms and to help prevent the development of further symptoms. If the source of bleeding can be identified, then surgical correction of the bleeding source can be performed [22].

Spinocerebellar degeneration, stroke, multiple sclerosis, cerebellar hemorrhage and infarction association with vestibulo-cerebellar disorders can all contribute to the development of chronic dizziness. Maladaptive postural adjustment to avoid the head motion(s) provoking dizziness can lead to the development of neck discomfort and headache, resulting in the prolongation of symptoms of dizziness. There is no known cure for these diseases, however physical therapy can be effective to slow down or modestly reverse the symptoms [35].

Specific Physical Therapy

Recently BPPV has been attributed to canalithiasis, the degenerative debris floating in the endolymph of the posterior semicircular canal. The particle repositioning maneuver for BPPV has therefore been recognized to be an effective treatment [36]. Repetitive positional exercise based on the hypothesis of cupulolithiasis is also helpful for the BPPV [37]. However, less than 5 % of all patients with BPPV are not successfully managed using this technique, and surgical intervention such as plugging the posterior canal may be considered. Osteoporosis due to a decrease of estrogen disturbs the internal structure of the otoconia and the attachment to the gelatinous matrix. The accompanying increased concentration of free calcium in the endolymph and a reduction in its capacity to dissolve the dislodged otoconia has also been reported [38]. Therefore, the management of osteoporosis may help certain BPPV patients suffering from recurrent BPPV [39].

Vestibular exercise (VE) is a specialized mode of physical therapy which consists of adaptation, substitution and habituation exercises. These exercises combine the use of visual, somatosensory, and vestibular cues to improve the gaze and postural stability in patients with vestibular deficits. The goal of VE is to facilitate CNS compensation and to reduce the impairments arising from chronic dizziness and disequilibrium and to promote the return to function. Visual-vestibular interaction exercises and adaptation exercises encourage the adaptation of the remaining vestibular system to rapid head motion in dizzy patients with unilateral vestibular disorder. Substitution exercises are used to improve balance and prevent falls by using visual or somatosensory input to substitute for absent or reduced bilateral vestibular function. Habituation exercises are used to reduce postural dizziness through repeated exposure to unpleasant stimuli. The VE can also be used to slow down or slightly reverse the symptoms of central vestibular disorders and Presbyastasis [40,41].

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Disclosure

There are no conflicts of interest.

References

1. Vidal PP, de Waele C, Vibert N, Muhlethaler M. Vestibular compensation revisited. Otolaryngol Head Neck Surg. 1998; 119(1): 34-42.
2. Curthoys IS, Halmagyi GM. Vestibular compensation: a review of the oculomotor, neural, and clinical consequences of unilateral vestibular loss. J Vestib Res. 1995; 5(2): 67-107.
3. Pfaltz CR. Vestibular compensation. Physiological and clinical aspects. Acta Otolaryngol. 1983; 95(5-6): 402-406.
4. Aoki M, Ito Y, Burchill P, Brookes GB, Gresty MA. Tilted perception of the subjective 'upright' in unilateral loss of vestibular function. Am J Otol. Nov 1999; 20(6): 741-747.
5. Black FO, Shupert CL, Peterka RJ, Nashner LM. Effects of unilateral loss of vestibular function on the vestibulo-ocular reflex and postural control. Ann Otol Rhinol Laryngol. 1989; 98(11): 884-889.
6. Solomon D, Shepard NT. Chronic Dizziness. Curr Treat Options Neurol. 2002; 4(4): 281-288.
7. Stroud MH, Newman NM, Keltner JL, Gay AJ. Abducting nystagmus in the medial longitudinal fasciculus (MLF) syndrome-internuclear ophthalmoplegia (INO). Arch Ophthalmol. 1974;92(1):2-5.
8. Nittner K, Petrovici IN. Contributions to the pathogenesis of Parinaud's syndrome. Vertical gaze paralysis following bilateral sterotaxic lesion in the interstitial nucleus region. Acta Neurochir (Wien). 1974; Suppl 21: 57-63.
9. Dix MR, Hallpike CS. The pathology symptomatology and diagnosis of certain common disorders of the vestibular system. Proc R Soc Med. 1952; 45(6): 341-354.
10. Hallpike CS. The caloric tests. J Laryngol Otol. 1956; 70(1): 15-28.
11. Gresty MA, Bronstein AM, Brandt T, Dieterich M. Neurology of otolith function. Peripheral and central disorders. Brain. 1992; 115 (Pt 3): 647-673.
12. Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. J Neurol Neurosurg Psychiatry. 1994; 57(2): 190-197.
13. Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory. Arch Otolaryngol Head Neck Surg. 1990; 116(4): 424-427.
14. Belal A, Jr., Glorig A. Dysequilibrium of ageing (presbyastasis). J Laryngol Otol. 1986; 100(9): 1037-1041.
15. Freeman R, Wieling W, Axelrod FB, et al. Consensus statement on the definition of orthostatic hypotension, neurally mediated syncope and the postural tachycardia syndrome. Clin Auton Res. 2011; 21(2): 69-72.
16. Hertzeanu H, Yahini JH, Neufeld NH. Holter monitoring in dizziness and syncope. Acta Cardiol. 1979; 34(6): 375-383.
17. Yardley L, Verschuur C, Masson E, Luxon L, Haacke N. Somatic and psychological factors contributing to handicap in people with vertigo. Br J Audiol. 1992; 26(5): 283-290.
18. Vermeer SE, Longstreth WT, Jr., Koudstaal PJ. Silent brain infarcts: a systematic review. Lancet Neurol. 2007; 6(7): 611-619.
19. Monsell EM. The mechanism of hearing loss in Paget's disease of bone. Laryngoscope. 2004; 114(4): 598-606.
20. Minor LB, Solomon D, Zinreich JS, Zee DS. Sound- and/or pressure-induced vertigo due to bone dehiscence of the superior semicircular canal. Arch Otolaryngol Head Neck Surg. 1998; 124(3): 249-258.
21. Valvassori GE, Clemis JD. The large vestibular aqueduct syndrome. Laryngoscope. 1978; 88(5): 723-728.
22. Schievink WI, Meyer FB, Atkinson JL, Mokri B. Spontaneous spinal cerebrospinal fluid leaks and intracranial hypotension. J Neurosurg. 1996; 84(4): 598-605.
23. Neuhauser H, Leopold M, von Brevern M, Arnold G, Lempert T. The interrelations of migraine, vertigo, and migrainous vertigo. Neurology. 2001; 56(4): 436-441.
24. Cady RK, Goldstein J, Nett R, Mitchell R, Beach ME, Browning R. A double-blind placebo-controlled pilot study of sublingual feverfew and ginger (LipiGesic M) in the treatment of migraine. Headache. 2011; 51(7): 1078-1086.
25. Aoki M, Ando K, Kuze B, Mizuta K, Hayashi T, Ito Y. The association of antidiuretic hormone levels with an attack of Meniere's disease. Clin Otolaryngol. 2005; 30(6): 521-525.
26. Aoki M, Wakaoka Y, Hayashi H, et al. The relevance of hypothalamus-pituitary-adrenocortical axis-related hormones to the cochlear symptoms in Meniere's disease. Int J Audiol. 2011; 50(12): 897-904.
27. Densert B, Sass K. Control of symptoms in patients with Meniere's disease using middle ear pressure applications: two years follow-up. Acta Otolaryngol. 2001; 121(5): 616-621.
28. Eklund S, Pyykko I, Aalto H, Ishizaki H, Vasama JP. Effect of intratympanic gentamicin on hearing and tinnitus in Meniere's disease. Am J Otol. 1999; 20(3): 350-356.
29. Huppert D, Strupp M, Brandt T. Long-term course of Meniere's disease revisited. Acta Otolaryngol. 2010; 130(6): 644-651.
30. Hain TC, Hanna PA, Rheinberger MA. Mal de debarquement. Arch Otolaryngol Head Neck Surg. 1999; 125(6): 615-620.
31. Schondorf R, Low PA. Idiopathic postural orthostatic tachycardia syndrome: an attenuated form of acute pandysautonomia? Neurology. 1993; 43(1): 132-137.
32. Cossu SF, Steinberg JS. Supraventricular tachyarrhythmias involving the sinus node: clinical and electrophysiologic characteristics. Prog Cardiovasc Dis. 1998; 41(1): 51-63.
33. Robertson D, Davis TL. Recent advances in the treatment of orthostatic hypotension. Neurology. 1995; 45(4 Suppl 5): S26-32.
34. Chrousos GA, Cowdry R, Schuelein M, Abdul-Rahim AS, Matsuo V, Currie JN. Two cases of downbeat nystagmus and oscillopsia associated with carbamazepine. Am J Ophthalmol. 1987; 103(2): 221-224.
35. Phanthumchinda K, Srikiatkachorn A. Spinocerebellar degeneration. J Med Assoc Thai. 1991; 74(2): 71-79.
36. Epley JM. The canalith repositioning procedure: for treatment of benign paroxysmal positional vertigo. Otolaryngol Head Neck Surg. 1992; 107(3): 399-404.
37. Brandt T, Daroff RB. Physical therapy for benign paroxysmal positional vertigo. Arch Otolaryngol. 1980; 106(8): 484-485.
38. Zucca G, Valli S, Valli P, Perin P, Mira E. Why do benign paroxysmal positional vertigo episodes recover spontaneously? J Vestib Res. 1998; 8(4): 325-329.
39. Vibert D, Kompis M, Hausler R. Benign paroxysmal positional vertigo in older women may be related to osteoporosis and osteopenia. Ann Otol Rhinol Laryngol. 2003; 112(10): 885-889.
40. Shepard NT, Telian SA. Programmatic vestibular rehabilitation. Otolaryngol Head Neck Surg. 1995; 112(1): 173-182.

41. Cass SP, Borello-France D, Furman JM. Functional outcome of vestibular rehabilitation in patients with abnormal sensory-organization testing. Am J Otol. 1996; 17(4): 581-594.

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