Whiplash, Postural Control, and the Inner Ear

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Many patients with "whiplash syndrome" experience unremitting neck stiffness and pain. This abnormal muscular tension is postulated to be causally related to a central disorder of postural control, which has evolved secondary to injury of the inner ear labyrinthine structures. Moving platform posturography was used to demonstrate the presence or absence of a static or dynamic equilibrium disorder in 48 patients who had experienced the oscillation forces induced by a rear-end automobile collision. Other vestibular tests were used to document dysfunction of the semicircular canals and the otolithic structures. A high percentage of patients were found to have faulty inner ear functioning leading to inefficient muscular control of balance and erect posture. Active perilymph fistulas were identified at surgery in seven patients. [Key words: whiplash, inner ear postural control, perilymph fistula, vestibular, fibromyalgia, temporomandibular joint]

Approximately 10% of the occupants of the stricken vehicle in rear-end automobile collisions will develop "whiplash syndrome." The chronic symptoms may include head and neck pain, stiffness, malaise, disequilibrium, and the emotional disturbances of anxiety with depression. Approximately 50,000 new patients per year are added to those who are currently experiencing this medical enigma.18

Macnab7 studied 575 patients with hyperextension neck injuries for several years. His studies suggested that many of the diverse symptoms of patients with whiplash injury have a poorly understood pathophysiological basis. This group of patients rarely had evidence of overt neck injury, nor was neurologic damage noted. Therefore, more covert structural damage and subsequent physiologic derangements must obtain. Areas where such damage might occur include the brain, the brain stem, certain cranial nerves and cervical nerve roots, and the inner ear labyrinthine structures (Figure 1).

The focus of this clinical study was to find out if the oscillation forces of whiplash injury could cause demonstrable inner ear dysfunction and a resultant disorder of postural control. The postural control changes would be reflected in abnormal muscular tension states in the antigravity extensor muscles of the head and neck and in a demonstrable disorder of balance and equilibrium (Figure 2).

MATERIALS AND METHODS

Patients. During an 18-month period ending in January 1987, 48 patients with persisting whiplash symptoms were referred for chronic pain management. The patients were evaluated for evidence of orthopedic or neuromuscular injury residuals and for balance and equilibrium dysfunction. Most of the patients had been previously evaluated by orthopedic or neurologic specialists and in general, the injuries were considered to be minor "soft tissue" cervical injuries. Symptoms were considered to be excessive and inordinately prolonged. The presence of "cervical vertigo" was noted when the patient had an abnormal postural control response and subjective dizziness to rotational movements of the body under a stationary head.

There were 30 female and 18 male patients. The oldest patient was 65 years old and the youngest 14 (mean age, 36 years). The time spread from injury to referral was from 7 months to 7 years.

Office Testing Procedures. Each patient was examined to determine spinal and major joint mobility, muscle strength and tonus, muscular tender points, and peripheral nerve integrity. Standard balance and coordination testing was performed.

A more refined series of tests were then given using vestibular test protocols developed by Tangan and Wheeler16 and Shumway-Cook and Horak.14 An office protocol was developed to access righting reflexes, static and dynamic equilibrium, and the patient's selection of balance strategies under a variety of conditions.

Laboratory Testing Procedures.

Moving Platform Posturography. Moving platform posturography (MPP) was developed by Nashner,6-11 and was designed to test motor functions related to balance while at the same time testing the patient's ability selectively to use visual, support-surface (proprioceptive), and vestibular orientation references. In cooperation with Black3-5 and Peterka,13 studies were performed on various patient groups and normative values established. Because the technique could isolate the inner ear gravitational references from the visual and somatic references, the vertical canal and otolith functions would be analyzed.

The MPP test report separates the motor test trials from the sensory test trials. Motor test data is returned concerning spinal reflex latency, response symmetry, force amplitude of responses, and electromyographic response patterns. Central nervous system (CNS) adaptation (ability to down scale motor responses to repeated perturbations) was analyzed.

The sensory test trials evaluate the contribution of the three major sensory inputs concerned with spatial orientation and balance. The data reflect the relative value of each sense to the patient and the patient's appropriate or inappropriate sense selection from the available references. After analyzing the test data, each patient was reported to have demonstrated a "normal" response pattern, a pattern suggesting a pure vestibular dysfunction, a visual preference response pattern, or a mixture of the two (Figure 3).

Tymanometric Fistula Test. This standard test for perilymph fistula has evolved from Hennebert's work (1905), as discussed by Grimm et al.6 The test is positive if sinusoidally modulated positive and negative air pressure into the external auditory canal produces nystagmus and, commonly, dizziness and nausea.

Plafond Fistula Test. If the preceding fistula test was positive, the technician was instructed to perform the platform fistula test. In this test, the patient stands with eyes closed on a force-recording platform while sinusoidally modulated air pressure is directed alternately to the right and left external canals. The test is positive if the standing patient sways in a phase-locked manner relative to the positive or negative pressure gradients.

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**Electronystagmographic Tests (ENG).** These standard tests were performed under the guidelines suggested by Barber and Stockwell and have several components. The oculomotor screening test, when abnormal, suggests an abnormality within the nonvestibular oculomotor pathways. Abnormal caloric studies, which test the horizontal (lateral) semicircular canals only, may show either hypofunction or hyperfunction on one or both sides. Positional tests are abnormal when nystagmus is spontaneous, direction fixed in three or more head positions, direction changing with changing head positions, or when vertical downbeat nystagmus occurs in one or more positions. These are nonspecific signs of peripheral vestibular or central abnormality. When placed in the Hallpike positions, a characteristic nystagmus will suggest the diagnosis of benign paroxysmal positional nystagmus (BPPN). This condition is the test expression of utricular otolithic damage with the same side posterior canal dysfunction due to cupulolithiasis (Figure 4).

**Rotation Chair.** This computer-controlled chair tests the vestibulocellular reflexes in great detail; it is able to examine the function of the horizontal canals to rotations of different frequency and direction.

**Audiometry.** This is a test battery for hearing. An abnormal test is noted when significant pure tone hearing loss is recorded (Table 1).

**Fig 1.** Schematic view of the inner ear from above. Sites of possible injury due to oscillation forces include: A) Stapes subluxation; B) Oval window fistula; C) Round window fistula; D) Utricle otolith injury; E) Posterior canal cupulolithiasis; and F) Saccule otolith injury.

**DISCUSSION OF PATIENT TEST DATA**

**Test 1: Moving Platform Posturography (48 Patients)**

**Motor Trials.** Three patients had abnormal tests on the spinal reflex portion of the trials. Patient 21 was found to have evidence suggestive of central brain stem involvement (direction-fixed downward nystagmus in several positions with ENG.) He also was found to have bilateral perilymph fistulae confirmed at surgery. A low frequency pure tone hearing loss was present. Patient 32 demonstrated an abnormal increase in reflex latencies on all trials and an unexplained quadriiceps tremor. She had positive fistula tests but was lost to follow-up. Patient 35 demonstrated disordered and asymmetrical muscle reflex latencies without clinical correlation. She also showed failure of central adaptation and maladaptive (co-contraction) strategies in her efforts to maintain balance. The cause for these findings is unknown. The CNS adaptation trials were abnormal in 20 of the 48 patients. Because these patients had no clinical neuromuscular or musculoskeletal deficits and all had abnormalities in the sensory trials, this data is interpreted as representing inappropriate motor response strategies to sensory interaction abnormalities.

**Sensory Trials.** Five patients had normal patterns. Forty-two patients demonstrated abnormal responses in the six-step sensory-interaction trials. Patient 45 was reported to have an abnormal study due to
CNS involvement of oculomotor pathways. On oculomotor ENG testing, she was unable to maintain gaze fixation or static eye position. The cause for this was not found. Patient 43 was found to have a frontal lobe brain tumor (meningioma). The patient was lost to follow-up after her surgery to remove the tumor. Of the remaining patients, 9 had patterns resembling those patients with known peripheral vestibular deficiency, 7 had patterns recognized as similar to those patients with diagnosed BPPN (visual preference patterns), and 26 had patterns that were a combination of vestibular deficiency and visual preference.

Test 2: Tympanometric Fistula Test (42 Patients)

Twenty-six patients had a normal study. Sixteen patients had results suggestive of an active perilymph fistula in one or both ears.

Test 3: Moving Platform Fistula Test (21 Patients)

Twelve of the 21 patients tested positive for an active perilymph fistula in one or both ears. Seven patients subsequently underwent tympanotomy and repair of the fistula. The fistula was present on one side in one patient (Patient 3) and bilaterally in the remainder (Patients 4, 17, 21, 29, 36, and 46). Each of the patients had coexisting BPPN, which was treated with balance and habituation therapy.

Test 4: Electronystagmography (ENG) (28 Patients)

The oculomotor screening test was abnormal in two patients. Patient 45 was mentioned earlier. Patient 48 demonstrated a bidirectional interruption of slow visual pursuit consistent with central abnormality of oculomotor control. His caloric test data resembled one with severe motion sickness. He was very unstable on platform balance testing. It was thought that this patient had central concussion residuals affecting his balance rather than a peripheral vestibular disorder. Nine patients had abnormal ENG caloric testing indicating dysfunction of the horizontal semicircular canals. On positional testing, 18 patients demonstrated direction-fixed or direction-changing nystagmus on changes in multiple head positions. Performing the ENG recording while doing the Hallpike maneuver identified 16 patients whose recordings were suggestive of posterior semicircular canal dysfunction commonly seen in BPPN (otolith organ injury with posterior canal cupulolithiasis).

Test 5: Rotatory Testing (Nine Patients)

Of the nine patients tested with sinusoidal chair rotations, one showed abnormalities of the vestibulo-ocular reflex. This patient’s imbalance was thought to be caused by central and peripheral factors. Active perilymph fistulas were diagnosed and confirmed at tympanotomy.
Test 6: Audiometry (13 Patients)

Six of thirteen patients tested showed significant pure tone hearing loss. Two patients with low-frequency hearing loss had fistulas, and another fistula patient developed sudden unilateral hearing loss during the evaluation period. Patient 10 had inner ear hydrops.

Surgery

Seven patients had surgery to correct perilymbium fistula. Patient 2 had a single ear operated on. In her case, the stapes was rotated posteriorly and a leak found at the oval window. Patient 29 had right-sided stapes subluxation but bilateral round window fistulas. Patients 17, 21, 29, 36, and 44 had bilateral fistula repairs at separate surgeries. Approximately equal numbers of round and oval window tears were noted in these patients.

Fibromyalgia

There were 27 of the 48 patients whose history and physical findings identified them as having fibromyalgia (fibroitis syndrome) as described in a review article by McCain and Scudders. The vestibulospinal outflow is known to be largely responsible for the resting tonus of the antigravity extensor musculature including the jaw-closing muscles. This effect is mediated, at least in part, by adjusting the gain of the spinal cord fusimotor neurons and thus the feedback loop controlling the stretch reflex. The prevalence of fibromyalgia in more than 50% of the patients in this series suggests areas for further research. Temporomandibular joint (TMJ) problems were common in this group of patients, but the frequency was not documented.

DISCUSSION AND SUMMARY

The forces of the whiplash mechanism acting on the head and neck are surprisingly high. Research quoted by White and Panjabi states that an 8 mile/hr rear-end collision may result in a 2 g force acceleration of the impacted vehicle and a 5 g force acceleration acting on the occupant’s head within 250 msec of impact (1 g equals an acceleration of approximately 32 ft/sec). Ommaya and Hirsch showed that a 5 g force acceleration acting on the heads of monkeys and chimpanzees results in a 30% probability of brain stem injury, cerebral concussion, and cranial nerve stretch. Depending on the speed of the impacting vehicle and other variables, forces in the range of 5-30 g are possible.

In this series, 12 patients were diagnosed as probably having a perilymbium fistula, and in 7 of these, the diagnosis was confirmed at
surgery. Persistent stapes subluxation was noted in three cases. One explanation for this condition would be the different oscillation velocities of the middle ear ossicles and the skull in response to the sudden head acceleration.

Of the 28 patients who had ENG studies, 16 had patterns of nystagmus suggestive of BPPN. The BPPN may be bilateral but asymmetrical between the two ears. Eighteen patients had abnormal positional ENGs. These and the other abnormal test results suggest subtle but definite injury to the delicate labyrinthine structures or disorganization of their output at the vestibular level.

Of 48 patients tested with MPP, 43 had specific difficulties in maintaining balance with the test conditions. In the “vestibular deficient” group, nine patients were unable to maintain balance when forced to rely on vestibular information alone (vision and surface information neutralized). In the “visual preference” group (BPPN), seven patients could not suppress neutralized orientationally inaccurate visual information and formulated inappropriate postural response strategies leading to falls. This occurred even when orientationally correct surface and proprioceptive information was available. The 26 patients with mixtures of these two patterns had variably severe difficulties maintaining balance. This material suggests a sensory input selection or integration disorder leading to inappropriate response strategies.

TREATMENT

The treatment of this group of patients followed a continuum starting with the most severe problem. In patients with active fistulas, a structured bed rest program was followed by apparent sealing of the leak in about half the patients. In those in whom healing was secure, residual balance problems and/or persistent BPPN were treated with a specific physical therapy program following the treatment protocol outlined by Tangeman and Wheeler and discussed more completely by Shumway-Cook and Horak. Patients who had surgical repair of the fistulas were managed in a similar fashion.

Patients with BPPN and vestibular deficiency responded well to habituation and balance training. Patients in whom motion sickness was a problem often required vestibular suppressant medication. Cervical mobility and strength were addressed by appropriate physical therapy. Relaxation training and counseling were helpful adjuncts. Return to an active lifestyle was encouraged as symptoms remitted, and return to work was usually possible. Once the patients came to understand the nature of their condition, compliance with treatment regimens was rarely a problem. As symptoms began to remit, most of the patients lost the anxiety and “hypochondriasis” that were present at the onset.

The patients with fibromyalgia also showed a gradual improvement with decreased general tension as well as a decrease in the number and sensitivity of tender points. A number of patients with this condition were benefited by low dosage tricyclic antidepressant medication. Few of the TMJ patients required dental referral.

FINAL COMMENTS

Once the clinician or therapist becomes confident in the ability to test for the more subtle forms of static disequilibrium and learns to use the Hallpike maneuver with patients having a history suggestive of BPPN, the sooner this kind of patient can be referred for further testing and then started on diagnosis-specific treatment.

This paper has focused on the effects of whiplash oscillation forces on the inner ear and the postural control disorder that may follow. Brain, brain stem, and cranial nerve effects have been documented elsewhere; neuropsychologic tests can often demonstrate residuals of such injuries. The neck can also have a broad spectrum of injury. “Cervical vertigo,” if present, will often require skillful manual therapy in conjunction with balance and habituation training. The primary care physician must keep all these possibilities in mind when caring for these patients. Nine of 10 whiplash patients will respond to routine care; the 10th will require extraordinary management.

The availability of MPP for the evaluation of movement, balance and equilibrium disorders has led to a new understanding of the possibly major cause for the unrelevant neuromuscular hyperactivity of the head positioning muscles and the antigravity extensor musculature. Head and neck pain related to this phenomenon can be readily understood. The aural, visual, and autonomic symptoms along with the protracted illness behavior have an understandable physiologic basis and therefore can be more efficiently treated.*

REFERENCES


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