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Cervical Injury Assessments for Concussion Evaluation: A Review

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Background: A concussion is a complex pathophysiologic process that is induced by biomechanical forces and affects the brain. Cervical injuries and concussion can share similar mechanisms and nearly identical symptoms or causes. Therefore, symptoms or causes alone may be insufficient to differentiate between patients with a concussion and patients with cervical injuries.

Objective: To demonstrate the homogeneous causes and symptoms observed in patients with a concussion and patients with cervical injury and to provide information on clinical tests that can differentiate cervical injury from pathologic conditions of vestibular or central origin.

Summary: Given that concussion and cervical injury share similar causes and symptoms, this information alone may be insufficient to diagnose a concussion. Clinical assessments, such as the cervical joint-reposition error test, smooth-pursuit neck-torsion test, head-neck differentiation test, cervical flexion-rotation test, and physical examination of the cervical spine, can be performed after a head and neck pathomechanical event to identify the presence of cervical injury. Differentiating between a concussion and cervical injury is clinically vital for timely and appropriate evidence-based treatment.

Conclusions: Specific clinical tests should be used after a head and neck pathomechanical event to differentiate between symptoms due to a concussion and cervical injury. Continued research on the clinical utility of the 5 identified cervicogenic tests is also recommended.

Key Words: cervicogenic pain, cervical joint-reposition error, smooth-pursuit neck-torsion test, head-neck differentiation test, cervical flexion-rotation test

Key Points

- More research into the clinical utility and validity of clinical tests designed to isolate the origin of impairments is required to improve our understanding of the complex pathophysiologic components of concussion.
- Differentiating the symptoms of concussion and cervical injury is a vital part of concussion screening to ensure appropriate diagnosis, management, and treatment.
- Clinical tests are invaluable for differentiating among damaged structures and providing methods to measure improvements after treatment intervention.

The number of diagnosed concussions due to sport and recreation activities has been steadily increasing during the past few decades,[1] with an estimated 3.8 million concussions occurring in 2014.[2,3] This increase has been attributed, in part, to an improved comprehensive concussion-management approach.[2] The number of diagnosed concussions may also be related to the lack of diagnostic specificity, with concussion symptoms being attributed to different medical conditions, such as cervical injury.[3–5] For example, if patients exhibit dizziness, headache, or other symptoms after a collision, they are almost automatically diagnosed as having sustained a concussion. However, patients with cervical injury after a pathomechanical event affecting the head or neck may manifest nearly identical symptoms.[6]

Whereas concussion and cervical injury may induce almost identical symptoms, their treatment methods differ. Researchers[7] have thought that concussion management should include complete cognitive and physical rest until patients were asymptomatic, followed by a stepwise progression to return to participation. However, more recently, investigators[8–12] have suggested a comprehensive approach, including rest, pharmacologic intervention, vestibular therapy, oculomotor training, and balance training. Moreover, patients with cervical injury respond to immediate therapy, including soft tissue massage, passive stretching, strength training, cryotherapy, and thermotherapy,[4,13] and to pharmacologic interventions, vestibular maneuvers, and cervical manipulations.[4,13]

Researchers[8–14] have recently emphasized a targeted evaluation that focuses on all aspects of concussions, including possible involvement of the vestibular and cervical systems. In addition, acute treatment of identified conditions to ensure a restoration of various systems individually and collectively has been recommended. Gurley et al[10] noted the importance of understanding the mechanism of injury and observed that vestibular rehabilitation may be effective in patients with vertigo, dizziness, and poor balance resulting from a concussion-induced vestibular condition. Alsalaheen et al[11] further discussed

Table 1. Commonality Symptoms of Concussion and Cervicogenic Injury

Symptom	Condition	
	Concussion	Cervical Injury
Headache[3,10,15,16–19]	X	X
Dizziness[3,10,16–20]	X	X
Tinnitus[10]	X	X
Irritability[10,21]	X	X
Chronic traumatic encephalopathy[3]	X	
Sleep disturbances[3,10,17]	X	X
Blurred vision[10,17]	X	X
Neck stiffness[10,18]	X	X
Balance disturbances[13–17,20,21]	X	X
Depression[2,3]	X	
Cognitive deficits[10,17,21,22]	X	X
Memory deficits[10,17,18,21,22]	X	
Attention deficits[10,17,18,21,22]	X	X
Decreased cervical range of motion[18]		X
Decreased isometric neck strength[18]	X	X

the benefit of vestibular rehabilitation in pediatric concussion, noting that such treatment decreased not only the severity of self-reported dizziness but also self-reported measures of abnormal gait and balance. In addition, they observed improvements in conditions 1 (eyes open, fixed support) and 2 (eyes closed, fixed support) of the Sensory Organization Test.[11] Cognitive improvement has also been observed in patients with postconcussion syndrome (PCS) who underwent vestibular rehabilitation.[11]

Patients who have PCS after sport concussion and exhibit symptoms of dizziness, neck pain and tenderness, or headaches may have cervicogenic dysfunction. In a case series of 5 patients with PCS and neck pain, Marshall et al[4] observed self-reported improvements in symptom resolution after a cervical treatment comprising a series of manipulations and exercises involving the cervical vertebrae. Schneider et al[12] reported that participants who underwent combined vestibular and cervical spine rehabilitation programs were 3.91 times more likely to return to participation in less than 8 weeks than patients who did not undergo the therapy, suggesting that cervical therapy aided in the progression toward return to participation.

Therefore, the purpose of our review was to help clinicians diagnose and differentiate cervical injury and concussion resulting in vestibular or cephalic symptoms. We outline the injury definitions, causes, and symptoms of cervical injury and concussion to demonstrate their homogeneity. We then discuss how symptoms of these conditions can be differentiated based on structural involvement and through clinical testing. Finally, we discuss the benefit of including cervical injury assessments in the guidelines for managing and treating patients with concussion.

INJURY DEFINITIONS

Concussion is defined as a complex pathophysiologic process induced by biomechanical forces and affecting the brain.[4] Symptoms include headache; dizziness; disturbances in memory, concentration, and sleep; neck pain; irritability; blurred vision; vertigo; tinnitus; and fatigue (Table 1).[14–16] *Cervical injury* can be defined as persistent impairments caused by dysfunction of the somatosensory system of the cervical spine.[18,23] The symptoms are similar to those caused by concussion (Table 1)[17,21,22] and, whereas not fully understood, are likely caused by the strain placed on the soft tissue in the neck, which disrupts the afferent pathways that relay information from the neck to the brain.[24]

SIMILARITIES IN CAUSES AND SYMPTOMS OF INJURY

The mechanism of a concussion may involve either a direct or indirect blow to the head, neck, or another body part. Impulsive force generated by acceleration and deceleration of the skull can be transmitted to the brain microstructures, eliciting 1 or more symptoms.[4] These symptoms may be caused by multi-structural damage leading to system malfunction rather than by single-structure damage.[5,18,25] The mechanism of cervical injury is similar to that of concussion. Generally, neck pathomechanics have 4 phases: initial position, retraction, extension, and rebound.[18] Starting in the initial position, an impulsive force is transmitted through the cervical vertebrae, applying a substantial mechanical load to the neck musculature and surrounding soft tissues. During retraction, inertial acceleration forces the head and neck into extension. The passive constraints of the cervical musculature and ligaments limit extension and, in turn, are loaded. In response to this loading, the tissues rebound, injuring the neck's soft tissue.[6,14–16]

Researchers have investigated lingering symptoms that lead to PCS. Lau et al[17] reviewed available data on the acute symptoms of 107 concussed male high school athletes and found that dizziness predicted delayed recovery from concussion with an odds ratio of 6.34. In patients with cervical injury, the most commonly reported symptoms were neck pain, headache, dizziness, and neck stiffness.[18,22,26,27] The most common predictors of prolonged recovery were greater initial pain, total number of symptoms, and postinjury psychological factors.[28] In addition, tension of the cervical musculature is a diagnostic criterion associated with anxiety disorder and, therefore, is a predictor of persistent symptoms due to concussion and cervical injury.[29] Damage to the neck musculature and structures also has been linked to decreased neck-position sense. Viano et al[30] noted the importance of neck-position sense in injury prevention, reporting that, when the head was aligned with the torso at the moment of impact during a tackle, the maximal force was decreased by as much as 67%. In follow-up studies, researchers[20,31] have shown the direction of the impact may be vital in assessing the risk of an impact.

PHYSIOLOGY OF CERVICAL INJURY

Whereas a detailed review of anatomy and physiology is beyond the scope of this article, we provide a basic review of the potential effect of cervical spine somatosensory information on PCS and how appropriate testing can differentiate cervical spine involvement.

Afferents from the upper cervical spine provide somatosensory information for head and neck position, and multilevel integration of cervical somatosensory information occurs in the central nervous system. Cervical afferents have a complex neurophysiologic interaction with the

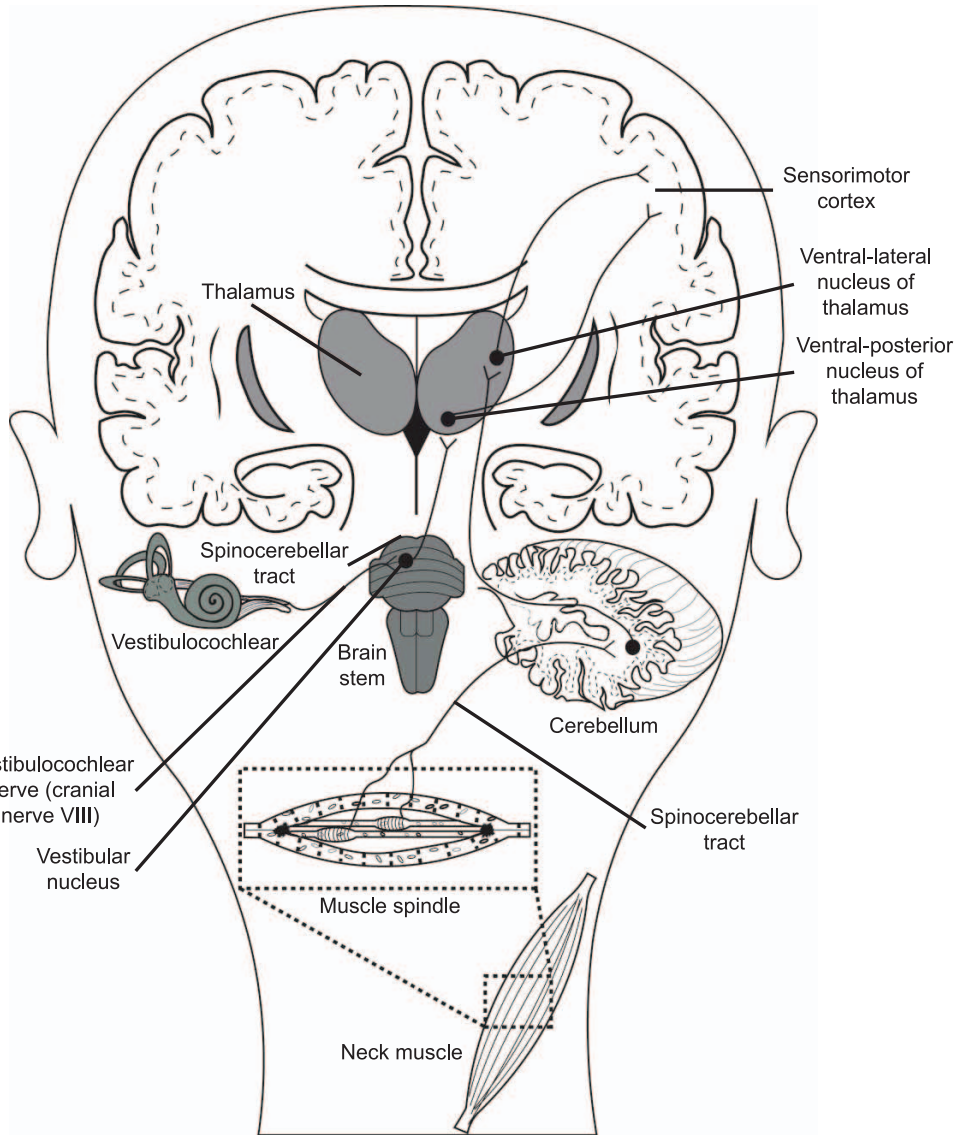

Figure 1. Major structures related to cervicogenic injury and concussive symptoms.

sensory and motor nuclei of the brainstem (Figure 1). In addition, cervical somatosensory information is integrated with visual and vestibular information in the cerebellum for adaptive postural and oculomotor regulation. Cervical afferents also project through the dorsal column/medial lemniscus to the thalamus and the primary somatosensory cortex for perception of head and body position and contribute to anticipatory ocular and postural adjustments during voluntary functional movements.[32]

Direct interactions of cervical afferents with the vestibular nuclei, superior colliculi, and central cervical nuclei help coordinate important reflexes required for gaze stabilization and postural stability. The cervicocollic reflex is mediated through the central cervical nuclei and works dynamically with the vestibulocollic reflexes to maintain head- and body-position alignment during functional movements.[28] Cervical afferents interact with the superior colliculi to produce the cervico-ocular reflex (COR) and can supplement the vestibulo-ocular reflex (VOR) to help stabilize gaze (eye stability) during head and neck movements.[33] The COR and VOR also work in conjunction with visual responses: smooth pursuit and saccadic control during visual tracking and scanning activities while the head and body are moving. In addition, cervicospinal and vestibulospinal reflexes use head- and neck-position information to contribute to postural tone regulation.[32]

Most cervicogenic symptoms have been attributed to injury or impairment of the upper cervical spine (C1–C3).[34] Researchers have suggested that abnormal somatosensory afferents arising from the muscle spindles, joint and pain receptors, or nerve roots of the cervical spine contribute to cervicogenic headache[34,35] and vertigo or dizziness.[34] Convergence of the C1–C3 cervical afferents with the trigeminal sensory afferents of the head and face in the trigeminal nuclei leads to referred hemicranial pain associated with cervicogenic headache.[36] Aberrant cervical somatosensory information may directly affect the cervical reflexes (cervicocollic reflex, COR, and cervicospinal reflex). The direct cervical inputs to the vestibular nuclei and superior colliculi may alter vestibular reflexes (VOR and vestibulospinal reflex) and ocular responses when abnormal cervical information is mismatched with normal

vestibular and visual information.[37] The sensory-information mismatch is thought to contribute to the symptoms of dizziness, disorientation, and balance disturbances associated with cervicogenic dizziness.[19]

CLINICAL TESTS TO ISOLATE AND DIFFERENTIATE CERVICAL INJURY FROM CONCUSSION

As clinicians better understand where injuries occur and which structures are involved, identification, treatment, and prevention become much easier. Therefore, a key to the differential diagnosis of cervicogenic syndromes is testing if cervical afferents cause symptoms or disruptions in balance and ocular motor control. Each test that we describe in this section attempts to remove visual and vestibular influences and isolate cervical position or movement-sensory information. The reproduction of symptoms or loss of motor-control accuracy during testing then can be attributed to cervical spine involvement. Patients perform tasks that require neck movement or stretch while the head maintains its position or rotates slowly enough to avoid perturbing the vestibular system. Whereas these tests often depend on subjective feedback from patients, current concussion examinations, such as the Sport Concussion Assessment Tool, third edition, and the Balance Error Scoring System, also rely on subjective observations. A categorized list of clinical tests that have been developed to target deficiencies in structures suspected of resulting in cervicogenic symptoms is given in Table 2.

Using the Delphi method, Reneker et al[40] surveyed experts in the fields of concussion, physical therapy, and neurology to identify the clinical utility of several clinical tests for differentiating between cervical injury and symptoms originating from the vestibular region or central processing after a sport-related concussion. The identified tests were the cervical joint-reposition error test (JPET), the smooth-pursuit neck-torsion test (SPNTT), the head-neck differentiation test (HNDT), the cervical flexion-rotation test, motor-control assessment of deep cervical flexors and extensors, and physical examination of the cervical spine. The symptoms, origin, positive sign, and suggested treatment for each identified positive clinical test are shown in Table 2.

The JPET was designed to test the ability to relocate the head to a starting neutral position after maximal rotation in the transverse or sagittal plane with the eyes closed.[41] Increased joint-reposition error indicates decreased sensorimotor control in the afferent pathway between the muscle spindles within the musculature of the cervical region and the central nervous system. The JPET has shown high sensitivity (82%) and specificity (92%) for identifying patients with cervical injury.[8] It is performed by attaching a laser pen to the top of the patient's head. A target is aligned with the point of the laser pen on the wall, and patients are instructed to close their eyes. They passively flex the neck and are instructed to return to the starting position. The process is repeated for extension and left and right rotation. After each trial, a mark is made on the target where the laser pen tip stops. The distance from the marked point to the center of the target is then measured.

Treleaven et al[27] recommended adding the SPNTT to the JPET for diagnosing cervical injury. During the SPNTT, patients sit or stand in a neutral position. They actively rotate the neck 45° to the right or left and perform an eye-tracking test (Figure 2). The test is designed to distinguish between conditions associated with the neck and posterior intracranial fossa or vestibular conditions emanating from the labyrinth in patients with similar symptoms. Tjell and Rosenhall[38] demonstrated the clinical utility of the SPNTT, reporting that neck torsion reduced smooth pursuit among patients with vertigo due to whiplash-associated disorders but did not reduce it among healthy control participants or patients with central or peripheral vertigo. In addition, they reported that the sensitivity and specificity of the SPNT for patients with cervicogenic dizziness were 90% and 91%, respectively.[38]

Figure 2. Smooth-pursuit neck-torsion test.

The HNDT is performed with the patient sitting in a chair that rotates (Figure 3). He or she is instructed to look at a point on the wall and hold the head still while the clinician rotates the body from under the seat. Whereas we found no research in which the HNDT was used to differentiate between cervicogenic and central conditions, Nelson and Viirre[42] indicated its utility in differentiating between patients with cerebellar infarction of a central origin and common vertigo generally thought to be cervicogenic. Figure 4 depicts a cervical flexion-rotation test that is performed with the patient in a supine position. The head is passively flexed to end range and held in that position. Next, the head is passively rotated to the left and right, taking care to perform all movements slowly to eliminate vestibular involvement.[43] In both tests, the provocation of

Table 2. Clinical Test Utility in the Diagnosis and Identification of Origin of Symptoms in Concussion Testing

Clinical Test	Positive Test	Origin	Symptom	Treatment	Criterion Validity	Advantages and Disadvantages
Cervical joint-reposition error test[8,37]	Increased error in repositioning the neck to a neutral starting position	Damage to muscle spindles in the neck	Neck pain and stiffness	Neck-position–sense training	Specificity = 92% Sensitivity = 82%	Advantages: inexpensive, quick, and objective Disadvantage: requires some equipment (ie, pen laser, target, and chair)
Smooth-pursuit neck-torsion test[32,38]	Performing tracking task in the rotated position evokes symptoms	Has been linked to disturbances in the neck	Cervicogenic dizziness, vertigo, and balance disturbances	Manual therapy and gaze-stabilization training	Specificity = 91% Sensitivity = 90%	Advantages: quick and can be objectively measured with equipment Disadvantage: subjective when addressing only symptom provocation
Head-neck differentiation test[40]	Head cannot hold still while body spins on chair or with other symptom provocation	Cervicocollic reflex	Dizziness, vertigo, and balance disturbances	Head- and neck-differentiation training	Specificity and sensitivity unknown	Advantages: quick, requires no equipment, and allows the clinician to isolate neck movement while holding the head still Disadvantage: limited to subjective report of symptoms
Cervical flexion-rotation test[29,39]	Onset of symptoms with head movement	Afferent information from cervical proprioceptors to central nervous system does not match other sensory information	Cervicogenic dizziness	Manual therapy	Specificity = 91% Sensitivity = 90%	Advantages: quick, requires no equipment, and movement is only at the neck Disadvantage: limited to subjective report of symptom provocation
Motor-control assessment of deep cervical flexors and extensors[39]	Inability to dissociate head and neck movements, failed endurance, and onset of dizziness with movement	Vestibulocollic reflex	Dizziness, vertigo, balance disturbances, and headache	Manual therapy	Specificity and sensitivity unknown	Advantages: quick and requires no equipment Disadvantage: limited to subjective report of symptom provocation

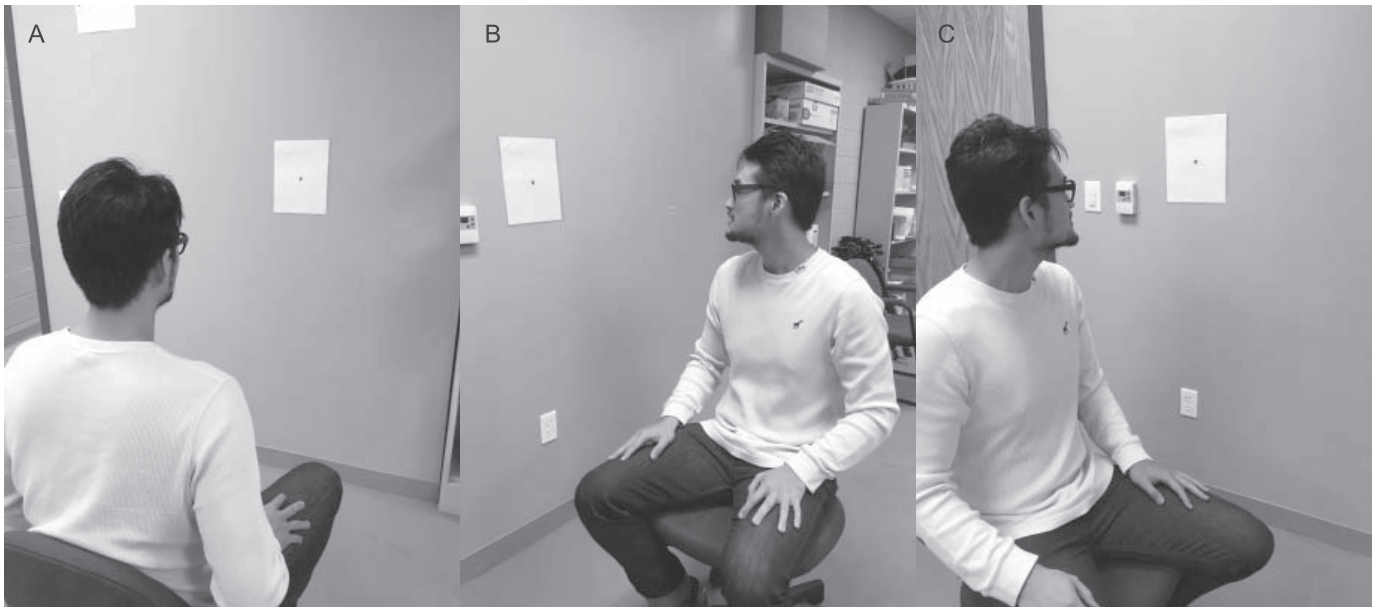

Figure 3. Head-neck differentiation test. A, The patient sits in a chair and looks at a point on the wall. B, The patient holds the head still as C, the clinician rotates the body from under the seat.

Figure 4. Cervical flexion-rotation test.

symptoms indicates a positive test. If symptoms increase with the test, cervical injury should be considered.

DISCUSSION

Reneker et al[40] hypothesized that the primary reason more clinicians were not incorporating cervicogenic tests into their routine evaluations of head trauma was a lack of education and awareness of the appropriate tests and methods. Current evidence-based practice guidelines and the *Athletic Training Education Competencies*, 5th edition,[44] do not recommend clinical testing to differentiate among cervical symptoms after a suspected concussion.

Both concussion and cervical injury are pathomechanical events affecting the head or body in which impulsive forces placed through the body and neck are transmitted to the brain; these conditions are diagnosed by the presence of 1 or more symptoms.[39,45] The distinct difference between the conditions is that concussions elicit symptoms due to brain damage, whereas cervical injury triggers symptoms due to neck-tissue damage. More specifically, symptoms associated with concussion are currently theorized to arise from damage to brain tissue via the shearing of axons that leads to a mass influx of intracellular calcium and mechanical injury to the peripheral organs, such as the otoliths, semicircular canals, and eyes.[46] Cervicogenic symptoms are thought to arise from damage to the proprioceptors involved in head- and neck-position sense.[5,46]

Properly determining whether concussion or cervical injury is the source of symptoms is vital because the management of each condition differs considerably. Current concussion management has evolved from the "rest-is-best" approach to an integrated, targeted approach.[8–12] Researchers[9,10] have suggested that complete symptom resolution may not be required before treatment begins, and symptom provocation should be the determining factor in progressing the treatment protocol. McCrea et al[16] explained that, whereas initial rest is important for the return of cognitive function and symptom resolution, an

integrated approach, including a return to graded exercise, pharmacologic aids, and vestibular therapy, may accelerate symptom resolution and return to activity.[9,10]

In patients with neck conditions and posttraumatic headache, the most effective treatment strategies are avoiding immobilization, resuming work, and undergoing comprehensive treatments.[47] Cervical manipulations, cryotherapy, thermotherapy, soft tissue massage, acupuncture, and passive stretching are effective interventions for patients with cervical injury.[4,21] In contrast, patients with a concussion gain little to no benefit from therapies that target the cervical spine. In addition, patients may present with both a concussion and cervical injury and may benefit from combining vestibular and cervical spine therapy, as demonstrated by Schneider et al.[12] Patients with both concussion and neck pain who received combined therapy were likely to return to participation within 8 weeks.[12]

Clinical tests are invaluable for differentiating among damaged structures and providing methods of measuring improvements after treatment interventions. If implemented appropriately, the aforementioned clinical tests could be incorporated in the diagnostic portion of a concussion screening to identify any deficits in cervical function and cervicogenic symptoms due to cervical injury after a head-neck segment pathomechanical event, leading to appropriate management and treatment of the diagnosed condition.

CONCLUSIONS

Whereas the symptoms and causes of concussion and cervical injury are similar, research into their potential overlap, precise mechanisms, and origins remains sparse. Additional investigation into the clinical utility and validity of clinical tests designed to isolate the origins of impairments is required to improve our understanding of the complex pathophysiologic components of concussion. Differentiating among symptoms is a vital step during the diagnosis of concussion to avoid a misdiagnosis, which could delay appropriate treatment and symptom resolution.

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