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Diagnostic Accuracy of Videofluoroscopy for Symptomatic Cervical Spine Injury Following Whiplash Trauma

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Abstract: Background: Intervertebral instability is a relatively common finding among patients with chronic neck pain after whiplash trauma. Videofluoroscopy (VF) of the cervical spine is a potentially sensitive diagnostic tool for evaluating instability, as it offers the ability to examine relative intervertebral movement over time, and across the entire continuum of voluntary movement of the patient. At the present time, there are no studies of the diagnostic accuracy of VF for discriminating between injured and uninjured populations. Methods: Symptomatic (injured) study subjects were recruited from consecutive patients with chronic (>6 weeks) post-whiplash pain presenting to medical and chiropractic offices equipped with VF facilities. Asymptomatic (uninjured) volunteers were recruited from family and friends of patients. An ethical review and oversight were provided by the Spinal Injury Foundation, Broomfield, CO. Three statistical models were utilized to assess the sensitivity, specificity, positive and negative predictive values (PPV and NPV) of positive VF findings to correctly discriminate between injured and uninjured subjects. Results: A total of 196 subjects (119 injured, 77 uninjured) were included in the study. All three statistical models demonstrated high levels of sensitivity and specificity (i.e., receiver operating characteristic (ROC) values of 0.71 to 0.95), however, the model with the greatest practical clinical utility was based on the number of abnormal VF findings. For 2+ abnormal VF findings, the ROC was 0.88 (93% sensitivity, 79% specificity) and the PPV and NPV were both 88%. The highest PPV (1.0) was observed with 4+ abnormal findings. Conclusions: Videofluoroscopic examination of the cervical spine provides a high degree of diagnostic accuracy for the identification of vertebral instability in patients with chronic pain stemming from whiplash trauma.

Keywords: whiplash; instability; videofluoroscopy; digital motion x-ray; positive predictive value

1. Introduction

Neck pain is a highly prevalent condition, occurring in 10–21% of the adult population annually [1]. A frequent cause of both acute and chronic neck pain is injury from a motor vehicle crash (MVC) [2]. Although a variety of spinal injuries are associated with MVCs, the most common injury type is musculoligamentous sprain or strain [3]. Such injuries often result from the type of whiplash trauma that is closely associated with rear impact crashes. The term "whiplash" refers to a traumatic whipping motion of the head and neck, primarily occurring in rear impact crashes, that produces higher peak acceleration at the head than in the neck or thoracolumbar spine [4]. While some authors have also used "whiplash" as a generic catch-all description for a variety of injuries resulting from whiplash trauma, when used to describe an injury the term generally refers to cervical spine sprain/strain injury [5].

A well-established feature of whiplash trauma is injury to the ligaments of the cervical spine, resulting in joint laxity and instability [6,7]. Intervertebral instability associated with ligamentous injury can be both difficult to detect and refractory to treatment [8]. Because the diagnosis of vertebral "instability" refers to an abnormality of function, the condition is typically not identifiable from static postural radiographs and may be occult to other conventional imaging (i.e., MRI and CT) and thus is prone to underdiagnosis [9].

A fluoroscopic examination of the spine (also known as videofluoroscopy (VF) or digital motion x-ray (DMX)) allows for a continuous and minute examination of movement within the cervical spine, including abnormalities of intervertebral motion associated with ligamentous instability [10]. Standard VF records 30 images per second of continuous x-ray of active range of motion across multiple planes, allowing for a dynamic four-dimensional visualization of the integrity of the ligaments of the upper, mid, and lower cervical spine [10,11]. Typically, cervical spine VF motion studies include a lateral view of flexion and extension (to examine anterior to posterior intervertebral instability) and anterior to posterior views of bilateral flexion with the mouth closed (to evaluate for excessive facet gapping in the mid and lower cervical spine) and the mouth open (to evaluate for lateral instability of C1 on C2). The studies provide evidence of the functional integrity of the ligamentum flavum, anterior and posterior longitudinal, interspinous, supraspinous and facet capsular ligaments in the mid and lower cervical spine (C2-7), and the alar and transverse ligaments in the upper cervical spine (C0-2) [7,8,12].

Although prior authors have examined the interrater reliability of VF for detecting cervical spine instability [13], at the present time there are no published studies describing the diagnostic accuracy (e.g., positive and negative predictive values) of VF for detecting symptomatic whiplash trauma-associated instability. The goal of the present study is therefore to provide a quantitative assessment of the ability of VF to discriminate between patients with symptomatic post-traumatic neck pain versus asymptomatic controls.

2. Methods

The study population was drawn from consecutive patients and patient relatives or acquaintances at 11 chiropractic or medical offices with an available on-site VF facility. Ethical oversight and approval was provided by a non-profit institutional review board (Spinal Injury Foundation-IRB00002637) in Broomfield, CO, registered with the US Department of Health and Human Services. Verbal informed consent was deemed adequate due to minimal risk, and was obtained from all study subjects in accordance with the IRB approved protocol. The inclusion criteria for all subjects was an age of between 16 and 65 years and an absent history of cervical fracture, congenital anomaly, inflammatory arthritis, diagnosed connective tissue disorders, metastatic disease of the spine, or any other bony or neurological abnormality that was deemed to potentially affect the results of a VF examination. Symptomatic (injured) subjects were recruited from patients actively seeking treatment for subacute or chronic neck pain persisting for more than 6 weeks after a traffic crash-related acute neck injury. Asymptomatic (uninjured) patients were recruited from relatives or acquaintances of patients presenting to the offices, and who did not, in the prior year, have a history of either chronic neck pain or episodic neck pain persisting for >1 week.

There were 5 VF motion view examinations of the cervical spine included in the study: 1) an anterior to posterior (A-P) view of the entire cervical spine, with right and left lateral flexion to the comfort of the patient; 2) A-P view of the upper cervical spine with the mouth open, with right and left lateral flexion to the comfort of the patient; and 3) lateral view with flexion and extension to the comfort of the patient, and 4–5) right and left oblique views with flexion and extension to the comfort of the patient. The limit of translation (slippage) used as the expected threshold for "normal" spines was 2 mm based on the so-called "rule of 2s" [14], as fewer than 10% of the spines of the uninjured and asymptomatic study group would be expected to exceed this degree of slip [15,16]. The upper threshold of normal intervertebral flexion used for the study was 10 degrees [17]. Other parameters used for assessing the VF studies are described in further detail in Table 1.

Table 1. Measured parameters of videofluoroscopy (VF) views/motions.

Anatomical/ Biomechanical Parameter (View)	Vertebral Level	VF motion Examination/ View Details	Measurement Details	Expected Normal Values
Lateral overhang (AP)	C1-2	A-P open mouth, R and L lateral flexion	Maximum difference in lateral translation (in mm) of the lateral margin of the lateral mass of C1 relative to the lateral margin of the superior articular facet of C2, between sides	2 mm or less overhang difference between sides
Peri-odontoid space symmetry (AP)	C1-2	A-P open mouth, R and L lateral flexion	Bilateral symmetry of gap between dens of C2 and medial margin of lateral mass of C1, observed at extreme R and L flexion	Symmetrical gap maintained
Translation (lat)	C2-7	Lateral flexion-extension	Maximum anterior (in flexion) or posterior (in extension) translation of vertebral body relative to adjacent inferior vertebra, measured at posterior vertebral body line	2 mm or less anterior or posterior translation
Intervertebral angulation (lat)	C2-7	Lateral flexion-extension	Angle between adjacent posterior vertebral body lines in maximum flexion	10 degrees or less
SP engagement (lat)	C2-7	Lateral flexion-extension	Degree of synchronous movement between adjacent spinous processes during flexion from neutral	Inter-spinous process distance increases commensurately with flexion
SP coupled movement (AP)	C2-7	AP c-spine R and L lateral flexion	Degree of coupled spinous process rotation with ipsilateral flexion	Spinous process rotates during lateral flexion
Facet gapping (AP)	C2-7	AP c-spine R and L lateral flexion	Degree of separation at facet during maximal lateral flexion	No appreciable gapping at maximum lateral flexion
Facet gapping (obl)	C2-7	R and L oblique c-spine flexion-extension	Degree of separation at facet during maximal forward flexion	No appreciable gapping at maximum forward flexion
Facet symmetry (obl)	C2-7	R and L oblique c-spine flexion-extension	Degree of symmetrical movement at facets during flexion and extension, comparing right and left	Movement and degree of gapping is symmetrical between sides

Abbreviations: AP = anterior to posterior view, lat = lateral view, obl = oblique view, mm = millimeters, R and L = right and left, SP = spinous process, c-spine = cervical spine.

Two raters trained in radiology and experienced in interpreting VF examinations evaluated the 5 studies of each patient for intervertebral movement from C1–C7. The raters were blinded as to prior interpretation of the studies. Details of measurement/assessment category choices for the VF readers are listed in Table 2. Where the raters disagreed, the more conservative (normal) of the 2 ratings was used to reduce the risk of Type I (false positive) error. The ratings were then dichotomized into either the "expected normal" finding or not (i.e., abnormal), as detailed in Table 2. Examples of normal and abnormal VF findings are depicted in Figures 1–4.