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# Addition of lateral bending range of motion measurement to standard sagittal measurement to improve diagnosis sensitivity of ligamentous injury in the human lower cervical spine

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## Abstract

**Purpose—**This study examined the cervical spine range of motion (ROM) resulting from whiplash-type hyperextension and hyperflexion type ligamentous injuries, and sought to improve the accuracy of specific diagnosis of these injuries.

**Methods—**The study was accomplished by measurement of ROM throughout axial rotation, lateral bending, and flexion and extension, using a validated finite element model of the cervical spine that was modified to simulate hyperextension and/or hyperflexion injuries.

**Results—**It was found that the kinematic difference between hyperextension and hyperflexion injuries was minimal throughout the combined flexion and extension ROM measurement that is commonly used for clinical diagnosis of cervical ligamentous injury. However, the two injuries demonstrated substantially different ROM under axial rotation and lateral bending.

**Conclusions—**It is recommended that other bending axes beyond flexion and extension are incorporated into clinical diagnosis of cervical ligamentous injury.

### Keywords

Ligamentous injury; Clinical diagnosis; Cervical spine; Range of motion measurement

## Introduction

Injuries affecting the cervical spine must be handled with great care, since the spinal cord and nerve roots are closely interspersed with the cervical vertebrae. The application of excessive stresses to the neural tissues can result in either transient or permanent neural

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Compliance with ethical standards

**Conflict of interest** None.

deficiencies [13, 14, 22]. These neurological tissues can be compromised by misalignment and/or extraneous motion between adjacent vertebrae, which are common results of hyperstrain injury to the cervical ligaments [4, 6, 12]. Ligamentous injuries are often the result of dynamic events such as vehicular accidents, head impact trauma, or even excessive stretching during exercise [3, 16].

Subfailure, ligament hyperstrain damage is not readily apparent from typical radiographs, which poorly visualize low-density tissues [17]. However, simple radiographs taken at the endpoints of a range of motion (ROM) test can detect hypermobility of the vertebrae, which may indicate the existence of ligamentous injuries. However, the effect that specific ligamentous injuries have on ROM is still vague, making these tests currently unreliable for detecting and diagnosing specific injuries, such as the difference between ligamentous damage resulting from hyperextension versus hyperflexion [4, 9]. Magnetic resonance (MR) has been reported to be only 70 % reliable in detecting ligamentous hyperstrain injuries [2, 5]. Hence, MR imaging is often not employed due to cost to benefit issues [2, 11]. Thus, there is a critical need to develop novel techniques that provide for the diagnosis of specific ligamentous injuries, ideally based on standard radiographic ROM measurement methodologies [3, 7].

In order to address the aforementioned need, previously developed finite element (FE) models were used to simulate whiplash-type hyperextension, hyperflexion, and simultaneous hyperextension and hyperextension injuries [10]. Whiplash-type injuries typically involve ligamentous hyperstrain damage and were studied by our group due to their high prevalence and associated societal costs [19]. Our group sought to determine if injury-specific kinematic signatures could be identified that would be clinically measurable.

## Materials and methods

The ABAQUS FE models (ABAQUS V6.9-EF2, Dassault Systèmes Simulia Corp, Providence, RI) used in the current study had previously been subjected to rigorous experimental validation for both intact (uninjured) and scenarios involving ligamentous injuries [10, 21]. Validation measures included intervertebral ROM, strain in the annulus fibrosus, cortical strain in the laminae, nucleus pulposus pressure, and facet contact pressure. Methods included cadaveric testing of whole cervical spines under ±0.75 Nm of pure moment loadings applied to C3 about all three primary bending axes of the spine (axial rotation, lateral bending, and flexion and extension) while kinematically constraining C7, as well as tensile measurement and physically simulated hyperstrain injury of individual ligaments.

The hyperextension injury was modeled by changing the mechanical definitions of the anterior longitudinal (ALL) and facet capsule (FC) ligaments. A separate and distinct hyperflexion model altered the properties of the ligamentum flavum (LF) and interspinous ligament (ISL). A third model was also created with simultaneous hyperextension and hyperflexion injuries. These ligament groupings were selected based on their hyperstrain injury prevalence in previous whiplash simulations [15, 23, 24]. Hyperstrain damage to these ligaments was simulated by reducing the mechanical preload and stiffness to values obtained from a previously published study [10]. The C5–C6 level was chosen for injury simulation as it is the most commonly injured region in the cervical spine [8, 15, 16]. ROM from these models were compared under all three primary bending axes of the spine to determine if each injury demonstrated a unique kinematic signature. These data were compiled into flowcharts in order to demonstrate how ROM measurements recorded during voluntary lateral bending and flexion and extension motions could be used to diagnose specific ligamentous injuries.

Uncertainty with respect to intertransverse tissue damage (including the intertransversarii muscles, intertransverse ligaments, and the vertebral artery) existed due to a lack of available data. Due to this ambiguity, these tissues were left intact in the experimental testing and a subset of the computational simulations. For the FE model, spring elements (ABAQUS type: SPRINGA) were placed between the transverse processes at the C4–C5, C5–C6, and C6–C7 levels to represent the passive stiffness of the muscles and aforementioned tissues. Measurements of the cross-sectional area of the tissues in conjunction with existing passive muscle tissue stiffness data indicated that 25 N/mm was an appropriate stiffness for simulating the intact intertransverse tissues [20].

The arrangement of the data into a clinical diagnostic tool was accomplished using percentage differences of the intervertebral ROM due to the specific injuries. This method allows clinicians to continue to utilize their favored datasets which define “normal” intervertebral flexibility. It also allows different methods of ROM measurement, whether intervertebral rotations are calculated from Cobb angles, span length between spinous processes, or by other means.

## Results

Comparison between the various injury cases revealed indistinguishable ROM for some loading cases, but noticeable differences for other loading scenarios (Figs. 1, 2). The hyperextension (FC + ALL) and hyperflexion (LF + ISL) ligamentous injuries resulted in nearly identical flexion + extension ROM. Only when measuring the flexion and extension ROM independently are the differing effects of the injuries revealed. Specifically, the FC + ALL injuries yielded a larger increase to extension ROM over intact cases than the LF + ISL injuries (1.15° vs 0°). This effect was reversed for flexion loadings (0.58° vs 2.07°). In contrast, both the lateral bending and axial rotation directions showed a more substantial ROM difference between the LF + ISL and FC + ALL injuries (lateral: 4.58° and 5.96°, respectively; axial: 6.65° and 8.02°, respectively). If the intertransverse tissues were damaged, the lateral ROM difference between LF + ISL and FC + ALL injuries was 6.42° and 10.08°, respectively, while the axial rotation ROM showed a contrast of 7.45° and 10.20° for LF + ISL and FC + ALL injuries, respectively.

## Discussion

The flexion and extension ROM tests showed a nearly indistinguishable difference between FC + ALL and LF + ISL damage, despite the injuries resulting from two different traumata (rear impact and frontal impact, respectively). Accordingly, ROM testing should not be limited to only flexion and extension, as is often the case [18]. While it was shown that the individual flexion and extension portions do indicate the specific injuries, it is difficult to determine when the spine passes from flexion to extension without knowing the neutral position of the intact spine, which varies between patients [1]. Without this knowledge, the common flexion and extension ROM test does not appear to be a good indicator for diagnosing specific injuries. However, the addition of frontal ROM measurement does reveal a distinction between hyperextension and hyperflexion injuries. Measurement of lateral bending ROM using standard radiographic and/or goniometric equipment in the clinical setting has demonstrated comparable accuracy and safety to flexion and extension measurement [9, 25]. Thus, the addition of frontal measurement to the typical sagittal ROM measurement protocol appears feasible. Sample diagnostic flowcharts that incorporate the frontal ROM measurement with sagittal ROM measurement are provided in Figs. 3, 4. Axial rotation ROM also offers a contrast between hyperextension and hyperflexion injuries, but may not be as readily measured through planar radiographs as lateral bending ROM.

One of the main limitations of the current dataset is the uncertainty regarding damage to the intertransverse tissues. In the lateral bending direction, ROM differs 57.0 % between the FC + ALL and LF + ISL injuries, but only shows a contrast of 30.1 % between these injuries if the intertransverse tissues are assumed intact. ROM data for both intact and injured intertransverse cases are supplied to help account for the uncertainty, but it is hoped that a future clinical study will definitively reveal the probability of intertransverse injuries in conjunction with injuries to the FC, ALL, LF, and ISL structures.

In conclusion, it was found that sagittal ROM tests are inadequate for deciphering between hyperflexion and hyperextension injuries. It is recommended that lateral bending ROM measurement is added to post-injury clinical measurement for more accurate diagnosis of ligamentous injuries.

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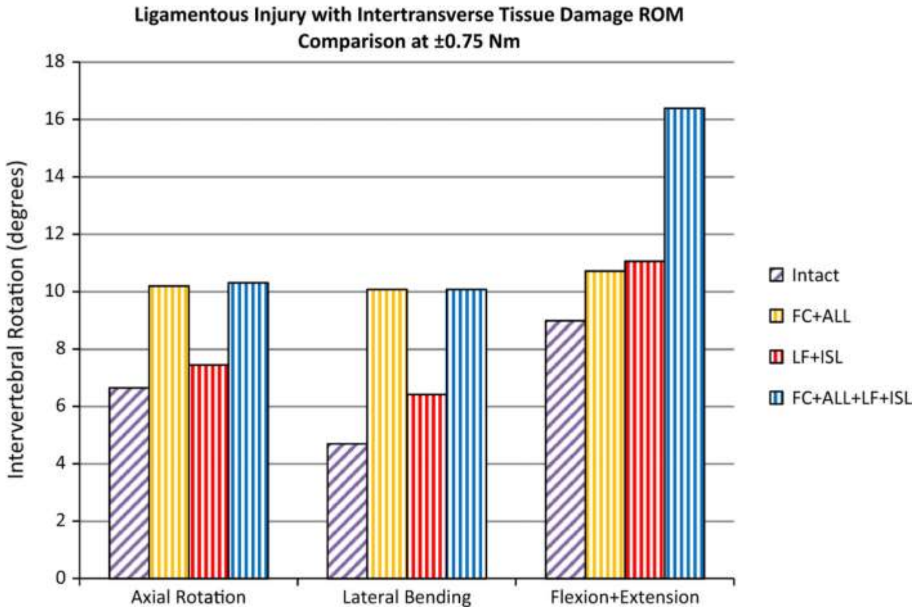

**Fig. 1.**

Comparison of FE-predicted C5–C6 intervertebral rotations for the various ligamentous injuries with intertransverse tissue damage due to a 0.75 Nm moment. Kinematic differences between the FC + ALL and LF + ISL cases are apparent in axial rotation and lateral bending, but not in flexion + extension

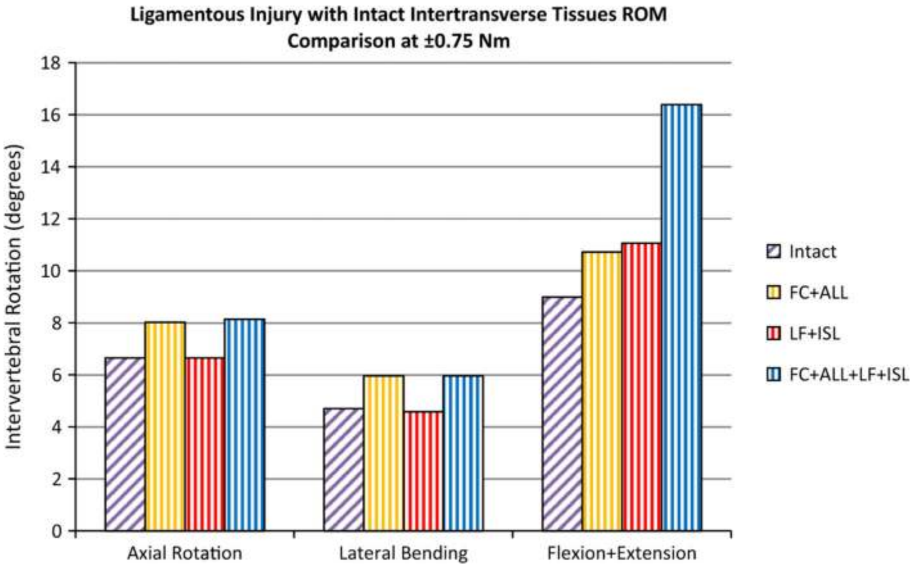

**Fig. 2.**

Comparison of FE-predicted C5–C6 intervertebral rotations for the various ligamentous injuries due to a 0.75 Nm moment. Kinematic differences between the FC + ALL and LF + ISL cases are apparent in axial rotation and lateral bending, but not in flexion + extension

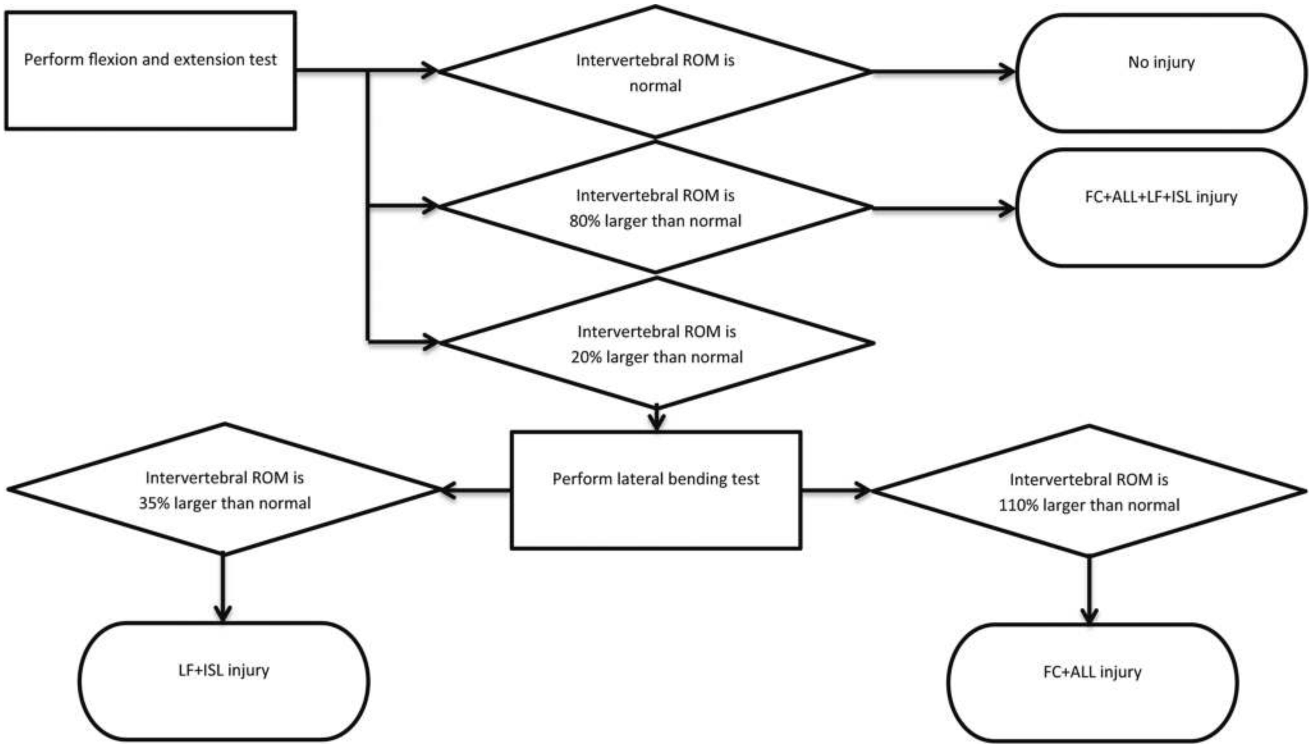

**Fig. 3.**
A sample diagnostic flowchart to be utilized with clinical range of motion test data assuming intertransverse tissue damage

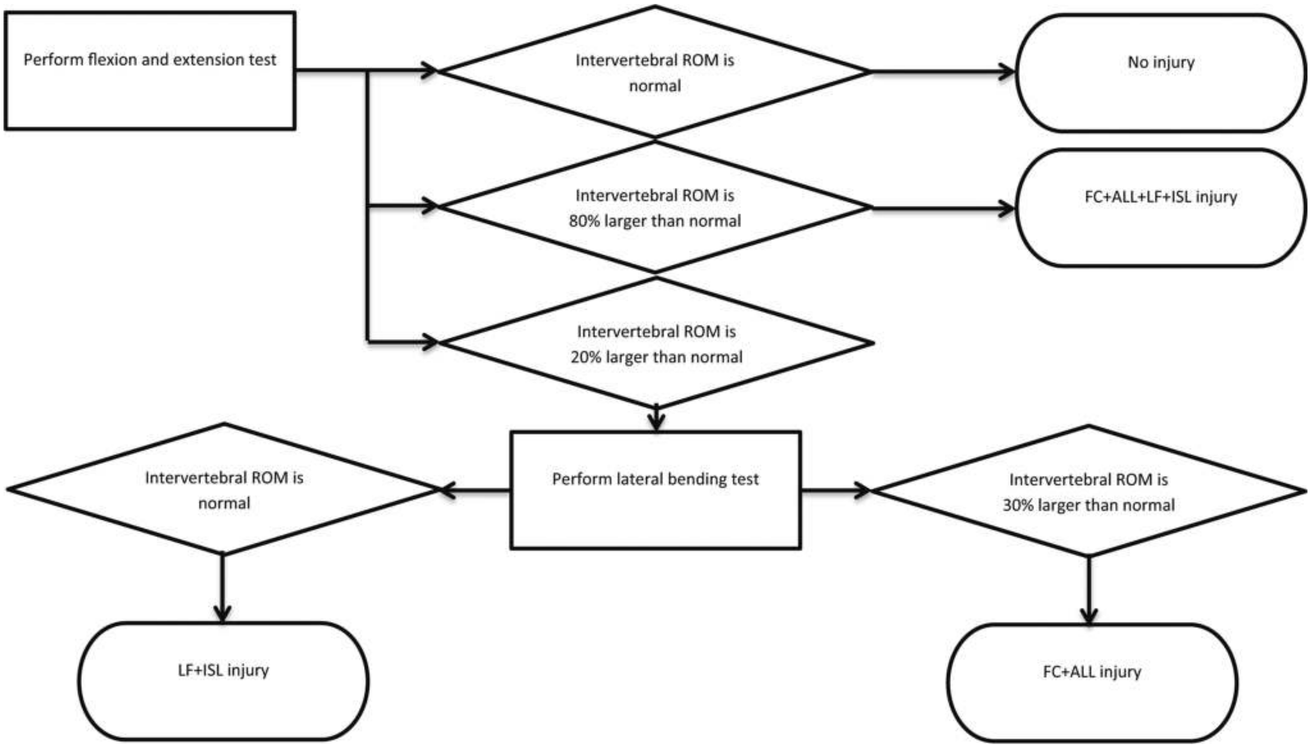

**Fig. 4.**

A sample diagnostic flowchart to be utilized with clinical range of motion test data assuming intact intertransverse tissues