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Comparison of human lumbar facet joint capsule strains during simulated high-velocity, low-amplitude spinal manipulation versus physiological motions

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Abstract

BACKGROUND CONTEXT: Spinal manipulation (SM) is an effective treatment for low back pain (LBP), and it has been theorized that SM induces a beneficial neurophysiological effect by stimulating mechanically sensitive neurons in the lumbar facet joint capsule (FJC).

PURPOSE: The purpose of this study was to determine whether human lumbar FJC strains during simulated SM were different from those that occur during physiological motions.

STUDY DESIGN/SETTING: Lumbar FJC strains were measured in human cadaveric spine specimens during physiological motions and simulated SM in a laboratory setting.

METHODS: Specimens were tested during displacement-controlled physiological motions of flexion, extension, lateral bending, and axial rotations. SM was simulated using combinations of manipulation site (L_3, L_4, and L_5), impulse speed (5, 20, and 50 mm/s), and pre-torque magnitude (applied at T_{12} to simulate patient position; 0, 5, 10 Nm). FJC strains and vertebral motions (using six degrees of freedom) were measured during both loading protocols.

RESULTS: During SM, the applied loads were within the range measured during SM in vivo. Vertebral translations occurred primarily in the direction of the applied load, and were similar in magnitude regardless of manipulation site. Vertebral rotations and FJC strain magnitudes during SM were within the range that occurred during physiological motions. At a given FJC, manipulations delivered distally induced capsule strains similar in magnitude to those that occurred when the manipulation was applied proximally.

CONCLUSIONS: FJC strain magnitudes during SM were within the physiological range, suggesting that SM is biomechanically safe. Successful treatment of patients with LBP using SM may not require precise segmental specificity, because the strain magnitudes at a given FJC during SM do not depend upon manipulation site.

Keywords: Manipulation, spinal; Zygapophyseal joint; Manipulation, chiropractic; Low back pain; Strain; Joint capsule; Facet joint; Lumbar spine

Introduction

In a recent national survey on patterns and perceptions of care [1], more people afflicted with back pain sought conventional therapy (such as physical therapy) versus chiropractic care (37% vs. 20%, respectively). However, patients who sought chiropractic therapy were more often satisfied with the treatment (61% vs. 37% seeking conventional therapy). This is concurrent with recent meta-analyses of randomized clinical trials that indicated that spinal manipulation (SM) was an effective treatment for low back pain (LBP), with rare incidence of serious adverse effects [2,3]. However, SM has evolved empirically and little is known about the physiological mechanisms by which it is effective [4].

The biomechanics of high-velocity, low-amplitude (HVLA) SM have been studied in vivo [4,5]. A patient is positioned side-lying with varying degrees of pelvic rotation.

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The practitioner administers a preload force on a single vertebral process (eg, lumbar mamillary process) to rotate the vertebra near the limits of its active range of motion. Then, an impulse load is applied such that the resultant displacement does not exceed the passive range of motion of the joint [4]. The preload force transmitted through the trunk approximates 100 N, and the transmitted force during the impulse, which is maintained for approximately 200 ms, ranges from 50 to 400 N [5–8].Vertebral motions during SM are relatively small (rotations: 1–2.5° [9]; translations: .25–1.62 mm [10]) as demonstrated by in vivo studies [9,10] and predictive modeling [11]. Although these studies provide useful information about the biomechanics of SM, the kinematics of the lumbar vertebrae using six degrees of freedom (DoF) during SM have never been quantified.

The vertebral motions that develop during SM load the facet joint capsule (FJC). The application of a HVLA SM in the L_3–L_5 region can result in "gapping" of the $L_{3\text{-}4}$, $L_{4\text{-}5}$, or L_5-S_1 facet joints [12]. The audible "crack" that often accompanies HVLA SM is believed to originate from a rapid distention of the facet joint surfaces causing cavitation within the synovial fluid [13]. Both phenomena imply that the FJC undergoes deformation (strain) during SM, though this has never been observed nor quantified.

The FJC is innervated with mechanoreceptors and mechano-nociceptors [14,15], and FJC strains (or stresses) during SM may be sufficient to stimulate these neurons. Mechanoreceptors innervating paraspinal tissues in cats responded in a graded fashion to the direction of an innocuous load applied to a lumbar vertebra [16]. Simulated SM can either increase or decrease the discharge of neurons innervating paraspinal tissues [17]. Large strains during SM may stimulate FJC mechano-nociceptors. Alternatively, high FJC strain rates could provide a novel stimulus for FJC mechanoreceptors [18].

It has been theorized that HVLA SM induces a beneficial neurophysiological effect by stimulating the mechano-sensitive neurons of the FJC [19]. The mechanical force delivered during SM or the biomechanical changes caused by SM may alter the inflow of sensory information from neurons innervating the paraspinal tissues to the central nervous system. These changes may reduce central sensitization, a phenomenon where the receptive fields of central neurons are increased and innocuous stimuli gain access to pain pathways [19]. Similarly, the pain-relieving effects of SM may also be the result of changes in neural plasticity, where afferent input resulting from SM could alter nociceptive circuits [20].

The purpose of the current study was to measure FJC plane strains during physiological motions and simulated SM. It was hypothesized that simulated SM would result in FJC strain magnitudes within the range that occurs during physiological motions, which would indicate that SM was a "biomechanically safe" procedure. It was also hypothesized that FJC strain magnitudes would be independent of manipulation site, which would indicate that the effects of SM may also occur distal to the manipulation site. Preliminary data have been presented in abstract [21] and thesis form [22].

Methods

Preparation of specimens

Intact human lumbar spine specimens (n=7; mean age: 64.3 years ±4.2 SD; range: 60–73; sex: 6 males, 1 female) were shipped frozen from the National Disease Research Interchange (Philadelphia, PA). Specimens (T_{12} - sacrum) were unembalmed and procured within 24 hours post-mortem from donors without history of spine pathology. All specimens were X-rayed (anterior-posterior and lateral views) to verify that they did not exhibit any gross pathology or substantial scoliosis (ie, >9°). Before testing, the spines were dissected free of all superficial soft tissue (including insertions of multifidi muscles) to expose the FJC. As was done in prior studies [23,24], the spinous processes were removed to facilitate the imaging of markers attached to FJC surfaces for plane strain measurements. Specimens were oriented such that the L_3 and L_4 end plates were horizontal to the testing surface, and were potted at the sacrum using a quick-setting epoxy (Bondo; Bondo Corporation, Atlanta, GA). Throughout testing, specimens were kept moist by periodic spraying with phosphate-buffered saline (PBS, pH=7.4) and by wrapping them in PBS-soaked gauze.

Physiological motions

The spines were tested during physiological motions of extension, flexion, left lateral bending, and right lateral bending using methods previously described in detail [23,24]. Briefly, the sacrum was rigidly fixed to the testing surface, and the T_{12} vertebral body was connected to a rod via a rigid U-shaped coupling with a pin through the middle of the vertebral body, allowing a single degree of freedom (Fig. 1a). The coupling was in series with a force transducer (Model XLS1-150; Load Cell Central, Monroeton, PA) (range ±660 N, resolution .07 N) mounted to a linear actuator (Model ME3528-406C; Galil, Inc., Rocklin, CA) by a low friction universal joint. As the spine was actuated, loads were applied without inducing a moment at the point of application. For all four motion types, a trial consisted of 10 cycles to 40 mm displacement (at T_{12}) at 10 mm/s. The magnitude of global spine displacement was selected from the prior study [23] as that which was largest in magnitude while producing moments at L5-S1 below a predetermined limit of 10 Nm (a threshold beyond which can produce load–displacement relationships suggestive of damage to soft tissues of the spine [25]).

After specimens were tested during motions of extension, flexion, and lateral bending, the spine specimens were prepared for testing during physiological motions of left and right axial rotation (Fig. 1b). Specimens were potted at T_{12} using the same quick-setting epoxy used to pot the sacrum.