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Differential displacement of soft tissue layers from manual therapy loading

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ABSTRACT

Background: Understanding the biomechanics of spinal manipulative therapy requires knowing how loads are transmitted to deeper structures. This investigation monitored displacement at sequential depths in thoracic paraspinal tissues parallel with surface load directions.

Methods: Participants were prone and a typical preload maneuver was applied to thoracic tissues. Ultrasound speckle tracking synchronously monitored displacement and shear deformation of tissue layers in a region of interest adjacent to load application to a depth of 4 cm. Cumulative and shearing displacements along with myoelectric activity were quantitatively estimated adjacent to loading site.

Findings: The cephalocaudal cumulative displacement in layers parallel to the surface were, in order of depth, 1.27 (SD = 0.03), 1.18 (SD = 0.02), and 1.06 (SD = 0.01) mm ($P < 0.000$), respectively. The superficial/intermediate shear was 2.1 ± 2.3% whereas the intermediate/deep shear was 4.4% (SE = 3.7, $P = 0.014$). Correlation of tissue layers was stronger with application site displacement at the surface ($0.87 < r < 0.89$) than with muscle activation ($0.65 < r < 0.67$).

Interpretation: Surface loading of the torso in combined posteroanterior and caudocephalic directions result in both displacement of tissues anteriorly and in shearing between tissue layers in the plane of the tissues strata to depths that could plausibly affect spinal tissues. Displacements of tissues more likely arise passively, consistent with load transmitted by the retinacula cutis and epimuscular force pathways. Displacements are similar in magnitude to those known to evoke biologically relevant responses in both animal and human studies.

1. Introduction

Typically, high-velocity, low-amplitude (HVLA) spinal manipulative procedures are applied to the body surface using a ramped increase in load, termed the preload phase, followed by a single impulse load designed to influence the underlying spinal joint. Different intensities (Snodgrass et al., 2014) and rates (Cleland et al., 2009) of manual loading appear to have stronger clinical effects than others. It is not yet clear how these differences propagate through the tissues and are modulated. A complete understanding of the biomechanics of manipulative therapy requires knowing the manner in which loads are transmitted between the surface application site and the deeper tissue layers and bone (Pickar, 2002). The differential response among the tissue layers may supply clues to mechanotransduction triggers and the ability to systematically modulate effects. Indeed, the whole question on whether loads are transmitted through the tissues in any controlled way to suggest a feasibility of dosing effects is a matter of controversy. The administration of loading parameters can be systematically controlled (Descarreaux et al., 2005; Descarreaux and Dugas, 2010, Triano et al., 2004, 2011, 2012, 2014, 2015), but how the soft tissues attenuate, absorb or redistribute those loads is not clear. Bereznick et al. (2002) as well as Kawchuk and Perle (2009) have measured the difference between applied load components and transmitted loads in human and porcine models, respectively. They postulate that therapeutic procedures may contain a significant component of "wasted energy" as a result of low friction coefficients between tissue layers (Bereznick et al., 2002), perhaps further constrained by the motion segment geometry (Kawchuk and Perle, 2009). Both studies suggest that little more than a tissue compression effect is transmitted posteroanteriorly.

Our goal was to directly monitor both posteroanterior and caudocephalic motion of tissue in strata at sequential depths between the load application site and targeted spinal segment in the paraspinal thoracic region. Using relative tissue displacement measured by

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ultrasound elastography as a surrogate for evidence of load transmission. We hypothesized that an HVLA preload maneuver would result in a superficial to deep sequential engaging of tissues underlying the skin. The preload phase was selected because of its known superficial tissue displacement behavior (Bereznick et al., 2002; Kawchuk and Perle, 2009) and ability to influence physiologic responses to treatment (Nougarou et al., 2014) but absent the highly dynamic elements of the impulse phase. Data of this type will help clarify how therapeutic loads interact with tissues to transfer effects through them. Such understanding will contribute to future work seeking to optimize treatment outcomes for patients receiving manipulative procedures in managing their pain and functional impairment.

2. Methods

A pre-post test experimental study design was used to evaluate the motion of subcutaneous tissue layers during the application of manual preload forces to the thoracic region of healthy volunteers. Ultrasound speckle tracking techniques (Konofagou and Ophir, 1998; Langevin et al., 2011; Ophir et al., 1991) were used to monitor the displacement and shear deformation of the paraspinal soft tissues as the primary outcomes of the study. A number of biomechanical measures were monitored simultaneously to define the experimental environment including forces transmitted through the thorax, displacement of the application hand and torso, as a rigid body, and the ultrasound sensor.

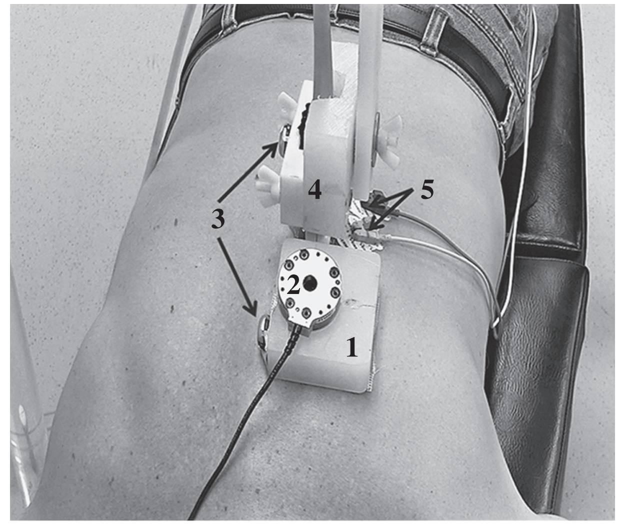

Fig. 1. Data capture configuration showing (1) the preload application block, (2) the ATI load cell, (3) infrared diode markers, and (4) clamped ultrasound transducer. An additional right acromion diode marker is not shown.

2.1. Participants

Twenty-four healthy male volunteers between the ages of 23 and 45 years were recruited from the population at the Canadian Memorial Chiropractic College (CMCC). Healthy subjects were selected for this study of mechanical effects on tissues to avoid variations due to any pathologic anomaly (Langevin et al., 2009). To control for any potential confounding effects from the presence of variable body fat depth, males with a mesomorphic body type, based on observation, were recruited (Kawchuk et al., 2011). All participants provided written informed consent that was approved by both the McMaster University Ethics (#12-594) and the CMCC Research Ethics (#122027) review boards.

2.2. Experimentation

Data were recorded from each participant during a single testing session. Prior to data capture, anthropometric data were obtained. The subject then laid prone on a treatment table (Leander LT 900, Leander Healthcare Technologies, Lawrence, KA, USA) that was modified with an embedded AMTI force plate (Advanced Medical Technology Inc., Model; OR6-7, Watertown, MA, USA) located beneath the thoracic torso support surface (Triano et al., 2012). Each subject was positioned with a standard alignment of the L4/L5 intervertebral disc at the caudal edge of the thoracic support (Fig. 1). The participant's arms were positioned at the side and internally rotated below the elbow. The inferior angles of the scapulae were identified as consistent landmarks between subjects. An acrylic block (2 cm thick × 4 cm wide × 4 cm long) was adhered to the skin overlying the erector spinae and centered approximately 2 cm left and 2 cm superior to the spinous process at the level of the left scapula's inferior angle using commercial double-sided tape to provide a uniform surface for distributing the manually applied force to the underlying tissues. The block was machined to fit a 6 degrees of freedom force transducer (ATI industrial automation, F/T model; mini 45E, Apex, NC, USA) for recording the applied forces and moments. The initial orientation angle of the block with respect to the horizontal was measured with an inclinometer to the nearest degree and, based on preliminary testing, was assumed to remain unchanged throughout the experimental maneuver. Activity of the underlying thoracic paraspinal muscle was monitored by a pair of Ag-AgCl electrodes (Biopac Systems Inc., Goleta, CA, USA), separated by a center-to-center inter-electrode distance of approximately 3 cm, that were adhered to the skin. Placement was arranged to record directly caudal to the loading site at approximately the T7 segment (Cramer and Darby, 2005). Electrodes were covered with Opsite tape (Smith and Nephew, Mississauga, ON, Canada) to insulate them from the ultrasound gel. An ultrasound transducer (Sonix RP, Burnaby, BC, Canada) was positioned medial to the electrodes, aligned parasagittally, approximately 2 cm left of the spine's midline (Langevin et al., 2009, 2011) and held in position by an independent, floor-mounted clamping system. The recording locations, as described, limited the characterization of behavior to those tissues caudal to the application site.

In the parasagittal plane, two ultrasound recording sites were identified. The first (proximate) site was located directly caudal to the loading block. The second region (distant site) was also 2 cm lateral to the midline and caudal to the proximate site. The caudal location was standardized as one-third of the distance from the load application site to L5/S1.

A single optoelectronic camera (Optotrak Certus System, Northern Digital Inc., Waterloo, ON, Canada) was positioned 2.5 m to the side of the participant. Infrared-emitting diode markers were placed in three locations to monitor relative body segment displacements. One marker was affixed to the acrylic block through which loads were applied. A second was positioned on the ultrasound head while the third was placed over the subject's right acromion process to monitor any concurrent torso displacement during the experimental maneuver.

2.2.1. Experimental maneuver

Two experimental maneuvers were performed sequentially, first with the ultrasound recording at the proximate site and secondly with it at the distant site. All data capture was time-synchronized based on an independent signal triggered by initiating the ultrasound capture. After sonation began, a clinician with 6 years of experience in manual therapy applied force to the subject through the load cell and acrylic block. The force modeled the typical “preload” phase that is designed to induce tension in the underlying tissues before a high-velocity and low-amplitude (HVLA) thrust would be applied. The direction of force was caudocephalic and secondarily posteroanterior with respect to the subject's torso. During the maneuver, the block was allowed to displace cephalad (Fig. 2) until the clinician perceived maximal resistance to tissue movement. The total time for the experimental maneuver was less than 10 s.