ACC RAC Award Winning Paper

Development of a Linked Segment Model to Derive Patient Low Back Reaction Forces and Moments During High-Velocity Low-Amplitude Spinal Manipulation

Samuel J Howarth, PhD,[a] Kevin D'Angelo, DC,[b] and John J Triano, DC, PhD[c]

Abstract

Objective: The purpose of this paper is to present the experimental setup, the development, and implementation of a new scalable model capable of efficiently handling data required to determine low back kinetics during high-velocity low-amplitude spinal manipulation (HVLA-SM).

Methods: The model was implemented in Visual3D software. All contact forces and moments between the patient and the external environment (2 clinician hand contact forces, 1 contact force between the patient and the treatment table), the patient upper body kinematics, and inertial properties were used as input. Spine kinetics and kinematics were determined from a single HVLA-SM applied to one healthy participant in a right side-lying posture to demonstrate the model's utility. The net applied force was used to separate the spine kinetic and kinematic time-series data from the HVLA-SM into preload as well as early and late impulse phases.

Results: Time-series data obtained from the HVLA-SM procedure showed that the participant's spine underwent left axial rotation, combined with extension, and a reduction in left lateral bending during the procedure. All components of the reaction force, as well as the axial twist and flexion/extension reaction moments demonstrated a sinusoidal pattern during the early and late impulse phases. During the early impulse phase, the participant's spine experienced a leftward axial twisting moment of 37.0 Nm followed by a rightward moment of −45.8 Nm. The lateral bend reaction moment exhibited a bimodal pattern during the early and late impulse phases.

Conclusion: This model was the first attempt to directly measure all contact forces acting on the participant/patient's upper body, and integrate them with spine kinematic data to determine patient low back reaction forces and moments during HVLA-SM in a side-lying posture. Advantages of this model include the brevity of data collection (< 1 hour), and adaptability for different patient anthropometries and clinician-patient contacts. (J Manipulative Physiol Ther 2016;xx:1-9)

Key Indexing Terms; *Chiropractic; Lumbar Region; Biomechanics; Low Back Pain*

Given that high-velocity low-amplitude (HVLA) spinal manipulation (SM) has an inherent biomechanical link, substantial chiropractic research efforts have recently focused on quantifying biomechanical parameters associated with the HVLA impulse that seek to optimize patient safety, clinician education, and patient outcomes.[1–6] While each of the aforementioned studies have advanced our scientific understanding of the biomechanical control parameters involved with HVLA-SM, only one[1] has attempted to quantify the reaction forces and moments experienced by the low back of patients during HVLA-SM. Despite the use of a simplified model and making assumptions regarding the relationship between transmitted forces and those acting at the patient's low back, the processing of data was computationally demanding and time consuming. Results, while of academic interest, pragmatically were not easily available to inform educational, clinical, or research protocols.

Linked-segment models (LSMs) have been routinely employed throughout the biomechanics literature to quantify reaction forces and moments acting at specific joints in the body.[7–9] As the name suggests, reaction loads

[a] Associate Professor, McMorland Family Research Chair in Mechanobiology, Graduate Education and Research Programs, Canadian Memorial Chiropractic College, Toronto, Ontario, Canada.

[b] Graduate Resident, Department of Graduate Education and Research Programs, Canadian Memorial Chiropractic College, Toronto, Ontario, Canada.

[c] Professor, Department of Graduate Education and Research Programs, Canadian Memorial Chiropractic College, Toronto, Ontario, Canada.

Submit requests for reprints to: Samuel J Howarth, PhD, Associate Professor, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, Ontario, Canada, M2H 3J1. (e-mail: showarth@cmcc.ca).

Paper submitted April 16, 2015; in revised form June 22, 2015; accepted October 26, 2015.

0161-4754

http://dx.doi.org/10.1016/j.jmpt.2016.02.009

in biomechanics represent the net forces and moments supplied by the body's passive and active structures that counteract the action of external forces applied to a person's body and the inertial contributions produced by movement. To derive reaction loads at the lumbosacral joint (L5-S1) or the joint between the fourth and fifth lumbar vertebrae (L4-L5), these analyses can be performed using either a bottom-up (starting in the lower body and working up towards the pelvis) or top-down (starting in the upper body and working down towards the pelvis) approach.[7] For HVLA-SM a top-down approach is preferred primarily because of the greater ease in accounting for upper body segment orientations and geometry.

Recent technological advancements in instrumentation and biomechanical software have simplified the process for quantifying joint reaction forces and moments in biomechanics studies. The current report presents the experimental setup, as well as the development and implementation of a new LSM within a commercially available software package (Visual3D, C-Motion Inc., Germantown, MD, USA) that is capable of quickly deriving low back reaction forces and moments during HVLA-SM.

Methods

General Overview

The larger problem of performing a linked segment analysis during HVLA-SM can be broken into four smaller sub-problems:

1.) Determining the three-dimensional (3D) clinician hand contact forces, and the contact force between the patient and the treatment table. Included in this sub-problem is the task of locating the point of force application on the patient's thorax;
2.) Determining 3D rotational kinematics of the patient's thorax and pelvis;
3.) Scaling the model's anthropometry to reflect patient-specific anthropometry; and,
4.) Handling the relatively large time-series data to solve the equations of motion.

Participants

A single healthy male participant (27 years old, 1.83 m, 88.6 kg) without any current complaints of lower back pain was recruited since the primary goal of this work was to describe the model's development. Prior to data collection, the participant read and signed an informed consent document that outlined the instrumentation and experimental protocols that were approved by the Research Ethics Board at the Canadian Memorial Chiropractic College.

Instrumentation

An image of the entire experimental setup is presented in Figure 1.

Kinetics. The 3D contact force and moment between the participant's upper body and the treatment table was measured with a force plate (OR6-7, AMTI Inc, Watertown, MA), embedded within a chiropractic treatment table. The chiropractic treatment table had previously been designed to record forces and moments transmitted through the thorax during low back spinal manipulative procedures by using a break in the table at approximately the level of the target segment for treatment.[5] A pair of 6 degree of freedom (DOF) load cells (Mini45, ATI Industrial Automation Inc, Apex, NC) were used to measure applied forces and moments at the two contact locations between the clinician and participant's thorax.[10] One load cell was positioned over the participant's shoulder for the clinician's left hand contact, and the second was positioned over the L5 spinous process for the clinician's right hand/finger contact. Custom plastic objects were fabricated using a 3D printer (Airwolf3D HDL, Airwolf 3D, Costa Mesa, CA), and rigidly interfaced with each load cell to ensure that the clinician's hands only interacted with the participant through the load cells during the HVLA-SM. This mitigated the possibility for load sharing that can occur if either of the clinician's hands were to contact the participant's thorax in addition to the contact between the clinician's hands and the load cells. Analog voltages from the load cells and force plates were amplified (MiniAmp MSA-6, AMTI Inc., Watertown, MA, USA; FTIFPS1, ATI Industrial Automation Inc, Apex, NC) before being digitally converted using a ±10V range on a 16-bit analog to digital conversion board (Optotrak Data Acquisition Unit III, Northern Digital Inc., Waterloo, ON, Canada). All analog data were sampled at a rate of 1500 Hz.

Kinematics. Three-dimensional coordinates of active infrared light emitting diodes (IREDs) were recorded using 2 banks of optoelectronic cameras (Optotrak Certus, Northern Digital Inc., Waterloo, ON, Canada). Prior to data collection, the capture volumes of both cameras were registered and aligned to a common global coordinate system for the lab. Three IREDs were adhered to plastic flags that extended from each of the 6DOF load cells. Two additional sets of three IREDs were affixed to plastic plates that were held in place by belts strapped around the participant's thorax at the level of the spinous process for the ninth thoracic vertebra and pelvis. The fixed geometrical arrangements for each set of three markers defined local coordinate systems for separate rigid bodies, and the movement of each rigid body represented the 3D angular and linear kinematics of the segments/load cells to which they were attached.[11]

Prior to data collection, four points were digitized on each load cell. These points were used to identify the location and orientation of the load cells within the lab's