Clinical Biomechanics 29 (2014) 1099–1107

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Quantifying strain in the vertebral artery with simultaneous motion analysis of the head and neck: A preliminary investigation

Steven L. Piper [a], Samuel J. Howarth [a], John Triano [a], Walter Herzog [b,*]

[a] Canadian Memorial Chiropractic College, Toronto, Ontario M2H 3J1, Canada,
[b] University of Calgary, Calgary, Alberta T2N 1N4, Canada,

ARTICLE INFO

Article history:
Received 12 November 2013
Accepted 6 October 2014

Keywords:
Spontaneous vertebral artery dissection
Strain
Cervical spine
Kinematics
Spinal manipulation

ABSTRACT

Background: Spontaneous vertebral artery dissection has significant mortality and morbidity among young adults. Unfortunately, causal mechanisms remain unclear.

The purpose of this study was to quantify mechanical strain in the vertebral artery while simultaneously capturing motion analysis data during passive movements of the head and neck relative to the trunk during spinal manipulation and cardinal planes of motion.

Methods: Eight piezoelectric crystals (four per vertebral artery) were sutured into the lumen of the left and right vertebral arteries of 3 cadaveric specimens. Strain was then calculated as changes in length between neighboring crystals from a neutral head/neck reference position using ultrasound pulses. Simultaneously, passive motion of the head and neck on the trunk was captured using eight infrared cameras. The instantaneous strain arising in the vertebral artery was correlated with the relative changes in head position.

Findings: Strain in the contralateral vertebral artery during passive flexion-rotation compared to that of extension-rotation is variable ($[df = 32]: -0.61 < r < 0.55$). Peak strain does not coincide with peak angular displacement during spinal manipulation and cardinal planes of motion. Axial rotation displayed the greatest amount of strain. The greatest amount of strain achieved during spinal manipulation was comparably lower than strains achieved during passive end range motions and previously reported failure limits.

Interpretation: The results of this study suggest that vertebral artery strains during head movements including spinal manipulation, do not exceed published failure strains. This study provides new evidence that peak strain in the vertebral artery may not occur at the end range of motion, but rather at some intermediate point during the head and neck motion.

1. Introduction

Spontaneous vertebral artery dissection (sVAD), although low in prevalence rates (2.5–5 per 100,000 population), has significant mortality (23%) and morbidity, such as motor, sensory and cognitive deficits reported as high as 28% among young adults (Hassan et al., 2011). In addition, sVAD accounts for up to 25% of ischemic stroke in young adults <45 years old (Hassan et al., 2011). Given that stroke has an estimated annual cost of $73.1 billion (US) and that ischemic stroke accounts for 87% of all strokes, it follows that the approximate economic burden of sVAD may be up to $15.9 billion (US) (Lloyd-Jones et al., 2010). Unfortunately, causal mechanisms associated with sVAD remain unclear.

Case reports have described sVAD that occurred from movement of the head and neck during activities of daily living such as yoga, sleeping awkwardly, receiving dental work and cervical spinal manipulation (Haldeman et al., 2002; Haneline and Lewkovich, 2005; Kawchuk et al., 2008). These case reports, however, cannot be used to establish mechanisms of injury linking head and neck motion with sVAD. Previous clinical guidelines suggested provocative testing of the vertebral artery, including sustained rotation of the head on the neck, may help to elicit symptoms of sVAD (Magarey et al., 2004), while other studies report using positional testing, such as the extension-rotation test lacks validity (Cote et al., 1995). In addition, reports on cervical spinal manipulation as it relates to ischemic stroke are unclear about the type of manipulation delivered (Wynd et al., 2013). There is also variability that exists with application of spinal manipulation techniques between clinicians, and repeatability of consistent parameters, that makes interpretation of forces imparted difficult to assess (Descarreaux et al., 2012).

To date, we know that once a tear has occurred in the intimal lining of the vertebral artery (VA), blood may accumulate within the arterial layers; obstructing blood flow and leading to stroke (Kim and Schulman, 2009). Previous mechanistic studies have focused on hemodynamics and formation of embolisms, yet none of these explain the development of strain in the intimal lining that may lead to initial tearing of the VA (Callaghan et al., 2011). It is important to realize that although

---

* Corresponding author at: Faculty of Kinesiology, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1N4, Canada.
E-mail address: walter@kin.ucalgary.ca (W. Herzog).

http://dx.doi.org/10.1016/j.clinbiomech.2014.10.004
0268-0033/© 2014 Elsevier Ltd. All rights reserved.

trivial, certain motions of the head and neck may create more intimal strain than others.

A previous case–control study addressed the arterial stress placed on the internal carotid artery (ICA) during head movements in subjects who previously experienced spontaneous ICA dissection (Callaghan et al., 2011). The study made use of finite element modeling (FEA). The results suggested that stress placed on the intimal layer of the ICA is comparable in spontaneous ICA dissection patients versus healthy controls (Callaghan et al., 2011). FEA is a valuable tool, but relies on assumptions of constitutive equations, tissue dynamics and local deformations (Duan et al., 2009). FEA is typically employed when physical measurements cannot be determined and, therefore, independent validation of direct observation of the tissue stress and strain is lacking.

Mechanical failure of the ex vivo VA begins with a force of approximately 8.2 N to 8.8 N, and strain between 53% and 62% of its original resting length (Symons et al., 2002). Previous in vitro studies have reported peak VA strains up to 12.2% at the end range of head and neck motion in flexion/extension, lateral bending and axial rotation, with the largest strains being produced in axial rotation (Symons et al., 2002). Rapid neck movements, such as those produced during high-velocity, low-amplitude spinal manipulation (SM), have generated peak strains up to 12.9%, which is within the tolerable limits of VA (Herzog et al., 2012; Wuest et al., 2010). Previous in vitro studies have reported VA strains between 3.3% and 12.2% during motions of the head and neck in flexion/extension, lateral bending and axial rotation with the largest strains being produced in axial rotation (Symons et al., 2002). Rapid neck movements, such as those produced during high-velocity low-amplitude spinal manipulation (SM), generated strains ranging between 0.9% and 3.8%, which were considerably lower than strains observed during cardinal planes of motion (Herzog et al., 2012; Wuest et al., 2010). Measurements from previous work suggest that strain does appear to fluctuate based on head and neck movements, such as head rotation, although a degree of motion has yet to be determined (Wuest et al., 2010).

The complex anatomy and coupled motions of the cervical spine complicate interpretation of previous results on VA strain (Herzog et al., 2012). The VA branches off the subclavian artery (V1 segment), before traveling vertically through the transverse foramen of the cervical vertebrae from C6 to C2 (V2 segment) (Netter, 2006). As the VA exits through C1 transverse foramen, it makes a radical shift in its path (V3 segment). The V3 segment of the VA shifts from a vertical orientation into a horizontal as it travels posteriorly, before entering the occiput (Netter, 2006). The V3 segment of the VA is the most common reported site of an ischemic event and it also is noted for having the greatest amount of motion (Haldeman et al., 2002). One may hypothesize that due to the increased motion occurring in the V3 segment, there are large strains in the VA that may explain dissection of the artery at the V3 location. Ultrasonography has been used to estimate strain in the V3 segment during motions of the head. However, these strains have not been linked to either the segmental or global kinematics of the head and neck (Callaghan et al., 2011). Global kinematics of the head and neck are quantitatively reliable (Lansade et al., 2009) and are assumed to be bound biomechanically to segmental coupled motions to create arterial strain. Vertebral joint geometry and intersegmental tissue properties govern segmental motion coupling that sums to a global movement of the neck, with respect to the thorax.

The purpose of this study was to quantify the segmental mechanical strain in the VA, while simultaneously capturing kinematic data during passive global motion of the head and neck. In particular, flexion-rotation and extension-rotation, on the same side in cadaveric specimens, were quantified. Secondary aims include quantitatively describing the variability in strain between multiple cadaveric specimen segment levels during passive range of motion (RoM) tests, in addition to observing strain and global motion of the head and neck during SM with varying clinicians. Our null hypothesis was that the relative strain (elongation from neutral) in the VA at the V3 segment during maximum flexion-rotation passive RoM, was not associated with the strain in maximum extension-rotation passive RoM.

2. Methods

This study was approved by both the Canadian Memorial Chiropractic College Research Ethics Board and the University of Calgary Conjoint Health Research Ethics Board.

2.1. Study design

This study used a cross-sectional sample to observe a potential relationship between the measured VA strain and passive global motion of the head and neck relative to the torso during extreme combined displacements in the cardinal planes.

2.2. Sample specification

A convenience sample of three fresh, unembalmed, post-rigor cadavers was used. A priori sample size estimate indicated that six vertebral arteries (three cadaveric specimens) were required to achieve sufficient statistical power (see Justification of sample size and data analysis). Any excessive superficial plaque formation observed on the outside layer of the VA as a result of calcification of the VA was also noted, however not excluded. To ensure that relatively normal ranges of motions were observed, cadavers were excluded if, upon visual inspection after dissection, they were noted to have obvious osteophytes or other indications of bilateral osteoarthritis which could impede motion of the cervical spine. The experienced anatomist and experimenter came to agreement, on visual inspection, that ranges of motion would not be impeded. A RoM pre-screen was performed by an examiner, using a goniometer placed on the head of the cadaver. Side to side asymmetry, with a tolerance of 5° of variance, was allowed. If the cadaver did not achieve previously listed values, it was excluded from testing. Kinematic data obtained from the goniometer allowed for exclusion on the basis of previous RoM guidelines, determined in healthy living subjects (Lansade et al., 2009). Other exclusion criteria included visually observed damage to the VA at any level.

2.3. Description of experimental maneuvers

Following the RoM pre-screen evaluation, an experienced (10 years) anatomist exposed the anterolateral aspect of the VA, between each vertebral body segment, bilaterally using blunt dissection. A small incision was made above C1 at the V3 segment and also at each VA segment between the cervical vertebrae from C2 to C4 (V2). Piezoelectric ultrasonic crystals with a diameter of 0.5 mm (Sonometrics Corp., London, Ontario, Canada), were then sutured into the vertebral artery wall at

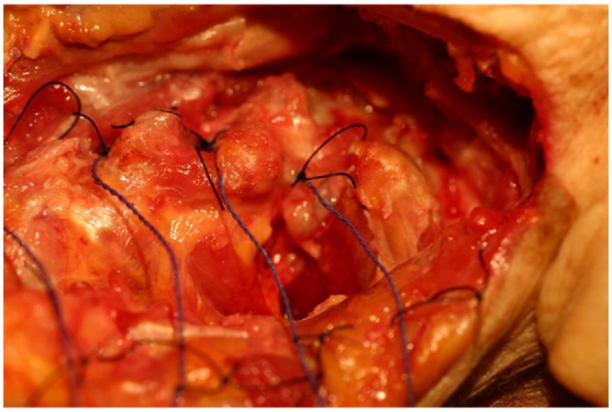

Fig. 1. Pictorial representation of piezoelectric ultrasonic crystals insertion into left VA.