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Changes in Vertebral Artery Blood Flow Following Various Head Positions and Cervical Spine Manipulation

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Abstract

Objective: The objective of the study was to investigate the cerebrovascular hemodynamic response of cervical spine positions including rotation and cervical spine manipulation in vivo using magnetic resonance imaging technology on the vertebral artery (VA).

Methods: This pilot study was conducted as a blinded examiner cohort with 4 randomized clinical tasks. Ten healthy male participants aged 24 to 30 years (mean, 26.8 years) volunteered to participate in the study. None of the participants had a history of disabling neck, arm, or headache pain within the last 6 months. They did not have any current or history of neurologic symptoms. In a neutral head position, physiologic measures of VA blood flow and velocity at the C1-2 spinal level were obtained using phase-contrast magnetic resonance imaging after 3 different head positions and a chiropractic upper cervical spinal manipulation. A total of 30 flow-encoded phase-contrast images were collected over the cardiac cycle, in each of the 4 conditions, and were used to provide a blood flow profile for one complete cardiac cycle. Differences between flow (in milliliters per second) and velocity (in centimeters per second) variables were evaluated using repeated-measures analysis of variance.

Results: The side-to-side difference between ipsilateral and contralateral VA velocities was not significant for either velocities ($P = .14$) or flows ($P = .19$) throughout the conditions. There were no other interactions or trends toward a difference for any of the other blood flow or velocity variables.

Conclusions: There were no significant changes in blood flow or velocity in the vertebral arteries of healthy young male adults after various head positions and cervical spine manipulations. (J Manipulative Physiol Ther 2014;37:22-31)

Key Indexing Terms: *Blood Flow Velocity; Manipulation Spinal; Hemodynamic; Head Movements; Vertebral Artery; Vertebrobasilar Insufficiency; Chiropractic*

Each year, stroke costs the Canadian economy $3.6 billion in physician services, hospital costs, lost wages, and decreased productivity.[1] Although rare in the general population, vertebrobasilar artery (VBA) stroke, such as spontaneous vertebral artery (VA) dissection, is a leading cause of nonatherosclerotic stroke in young adults.[2-4] It has been proposed that an underlying genetic predisposition, triggered by risk factors associated with environmental exposure, with or without trivial trauma may serve as an etiologic model.[5] However, the exact pathogenesis of VBA stroke is poorly understood.[4,6] It is well documented that patients who experience VBA stroke have a change in blood flow in the affected VA.[2,7,8] Others have noted signs and symptoms of vertebrobasilar insufficiency with certain head positions.[9-12] Authors speculate that mechanical compression or stretching of the VA at extremes of head position is a potential causative factor for VA blood flow change and is most likely to occur in the suboccipital

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part (V3) of the VA.[13-17] As a result of Bernoulli principle, there is an increase in blood flow velocity at and/or immediately beyond the point of constriction of a vessel owing to either stretching or compressive forces.[17] This may result in spurting and turbulent flow immediately downstream from the region of distortion[15] that may evoke a local thrombogenic response,[18] leading to VBA stroke. A change in VA blood flow after head rotation, especially contralateral to the direction of rotation, has been demonstrated in several studies.[17] However, these results yield some inconsistencies and are inconclusive with respect to clinical relevancy.[14,15,17]

There is continuing controversy about the effects of cervical range of motion and therapeutic physical interventions, including cervical spinal manipulation (CSM) and or sustained mobilizations, on the blood flow within the VAs and cerebrum. End-of-range motion, manipulation, and mobilization techniques are some of the common physical interventions used by manual therapists to treat neck pain and headaches. There are large well-designed epidemiologic, clinical studies and reviews reporting CSM to be a safe and effective treatment of neck pain and headache.[19-25] A recent population-based, case-control, and case-crossover study found that there was no excess risk of VBA stroke after chiropractic care for neck pain and headaches when compared with physician care.[21] At the ecologic level, the increase in VBA stroke does not seem to be associated with an increase in the rate of chiropractic use.[26] However, at the mechanistic level, few studies have examined the effects of CSM on VA blood flow. This has led to uncertainty on whether there is a potential risk in apparently healthy individuals for minor trauma or altered hemodynamics in cervical blood vessels from these maneuvers. Using Doppler ultrasound, Licht and colleagues[27] observed increased blood flow in the VA of dissected pigs lasting 40 seconds after receiving CSM. When examining the effects of CSM on human VA blood flow, Licht et al.[18,28] reported no significant difference in VA blood flow between a CSM group and a control group. The limited number of trials, inconsistencies within the results, and poor methodology make conclusions about the effects of CSM on VA blood flow difficult to interpret.

Ultrasonography studies are the most common techniques used to evaluate blood flow in the vertebral arteries. Although ultrasound techniques have been shown to be reliable, produce an image in real time, and are relatively inexpensive,[29-31] they are hampered by its user dependency, limited insonation angles, and unidirectional velocity encoding.[32,33] When imaging the vertebral arteries, there are additional challenges. Approximately 7% cannot be imaged because of their depth[34] and ultrasound waves cannot pass through bone, limiting visualization of portions of the VA that pass through osseous foraminae.[31] Furthermore, surface-based ultrasound lacks resolution when compared with other imaging techniques.[29,30,35,36] This limits visualization to only gross alterations in vessel size,[36] hindering the ability to locate any anatomical abnormality directly, and demonstrates the results of anatomical disruption as a variation in flow.[37] Subtle changes such as mild stenosis resulting in hemodynamic flow changes of less than 50% may also be missed by the ultrasound.[29,30,38]

Imaging blood flow across a range of cervical spine positions, including rotation and manipulation in vivo, under clinically relevant circumstances has the potential to provide a systematic estimate of alterations to the cerebrovascular hemodynamics. Magnetic resonance imaging (MRI) techniques such as phase-contrast magnetic resonance angiography have greater sensitivity than standard techniques such as Doppler ultrasound and are considered the criterion standard for both diagnosis of VBA strokes[8,29,37-39] and blood-flow volume quantification.[35,40] The intrinsic sensitivity of MRI to flow offers the possibility of analyzing blood flow hemodynamics without restrictions to anatomical coverage or flow direction.[33] Examining VA flow after various head positions and manipulation using phase-contrast MRI has yet to be reported. Therefore, the purpose of this study was to observe VA blood flow after manipulation and various head positions to assist in the understanding of the extent to which head/neck motion may interact with VA blood flow as a direct contributor to VBA stroke.

Methods

Participants

Healthy volunteers were recruited from the campus of a local chiropractic college. Included were healthy men aged 18 to 35 years who have received CSM, as part of their routine training program, within the last 3 months before data collection. Participants were judged to be clinically healthy based on a health-history questionnaire. Exclusion criteria included a history of disabling neck, arm, or headache pain within the last 6 months; any current or history of neurologic symptoms including facial or extremity weakness, abnormal sensation to the face, body, or extremities, uncontrolled movements, abnormal gait, dizziness, unexplained nausea/vomiting, difficulty with speaking or swallowing; or a history of claustrophobia. All participants also refrained from vigorous physical activity, alcohol, and caffeine 1 day before commencement of the study. The study was approved by the local ethics committees of St Joseph's Healthcare Hamilton at McMaster University in Hamilton, Ontario, and Canadian Memorial Chiropractic College in Toronto, Ontario. Written informed consent was obtained from all of participants before the study commenced. Data were collected at the Imaging Research Centre, Hamilton, Ontario. The study was registered with www.clinicaltrials.gov, NCT01205490.

This pilot study was conducted as a blinded examiner cohort with randomized clinical tasks, in which each participant received 4 head position conditions (neutral, 45° rotation, maximum rotation, and CSM). Tasks were selected based on their use in evaluation or treatment during clinical

Fig 1. *An example of C1-2 high-velocity, low amplitude cervical manipulation performed on an MRI pivotal table. (Color version of figure is available online.)*

encounters, and each neck rotation was performed to the side of the nondominant hand as per convention.[41]

Test Protocols

Before MRI, baseline information on each participants' height, weight, and hand dominance was collected to describe the study participants. Once positioned supine on the MRI table, each participant was randomly assigned 1 of the 4 test maneuvers. Maneuvers consisted of neutral (0° rotation) neck position (condition 1), 45° passive rotation (condition 2), maximum voluntary passive rotation within a comfortable range (condition 3), and a C1-C2 cervical rotatory manipulation (condition 4). Each head condition was applied in the MRI scanner room adjacent to the MRI bore (Fig 1) and was held for 1 minute and then returned to neutral position for MRI sequencing. For the manipulation, the head was repositioned at neutral immediately after the CSM, and light hand contact to the head and neck was maintained until 1 minute elapsed. Conditions 1 to 3 were independently measured by goniometry. After each condition, MRI of the upper neck for blood flow ensued. All participants received the 4 conditions in a randomized order. The total time elapsed for each participant testing protocol was 120 minutes. The total time elapsed for each condition was approximately 30 minutes. This included applying the condition (1 minute), replacing participant back into MRI bore (approximately 1 minute), anatomical images (approximately 20 minutes), and phase-contrast imaging (1 minute 30 seconds). Estimates of repeatability of flow measures were made in preliminary work by quantifying VA flow in a single healthy participant twice over a 2-month interval.

A practitioner with more than 30 years of practice experience conducted the upper cervical manipulation. The manipulation procedure required no transfer of the volunteer; rather, it was performed on the adjustable and pivotal MRI bed in the MRI room with the participant in the supine position (Fig 1). The procedure, a high-velocity, low-amplitude impulse, is designed to initially position the head in axial rotation as well as lateral bending and flexion postures,[42] where variations of head positions between operators have been shown to be relatively small.[42] The operator performed the procedures in representative manner, first establishing the end range of motion to determine appropriate preload position for the manipulation before applying a typical clinical force impulse in the coronal plane with minimal traction component. Before the delivery of each maneuver, the participant was queried on their comfort, condition, and willingness to continue. All participants completed the test protocols successfully with no adverse events.

A brief 5-item analogue scale was administered to each of the participants and clinician immediately after the test maneuvers. This scale provides quantitative estimates of the patient's and operator's judgment of the descriptive characteristics of the CSM procedure on a continuous scale of 0 to 10. The words "fast," "force," "comfort," "confidence," and "precise" were used as descriptors as validated and used in several other studies.[43-45] The scale provided a means of contrasting the procedure characteristics within the context of the range of typical performance, as represented within the literature.

Magnetic Resonance Imaging Protocols

Four MRI series were performed on each participant (3-Telsa GE Signa Excite HD MRI scanner and 12 channel neurovascular array RF coil; GE Healthcare, Milwaukee WI). At the level of C1-2, the contralateral and ipsilateral vertebral arteries (to the direction of head motion) were assessed and anatomical images were established to localize the VA circulation. As previously published by Ho et al,[40] the method for obtaining flow quantification of the VA was a 2-dimensional phase-contrast pulse sequence. To capture accurate VA flow, the imaging plane is ideally perpendicular to the central axis of the blood vessel. This imaging plane was selected on the vessel of interest at the C1-2 intervertebral level based on arterial visualization on a maximum intensity projection of a 2-dimensional time-of-flight MRI angiogram. Magnetic resonance acquisition parameters were as follows: fast gradient recalled echo; echo time/repeat time, 3.9/8.9 milliseconds; flip angle, 20°' 20 cm field of view; 512 × 512 matrix; 244-Hz/pixel receiver bandwidth; 1 average; 4 mm thick; and velocity encoding of 50 cm/s encoded for 30 phases per cardiac

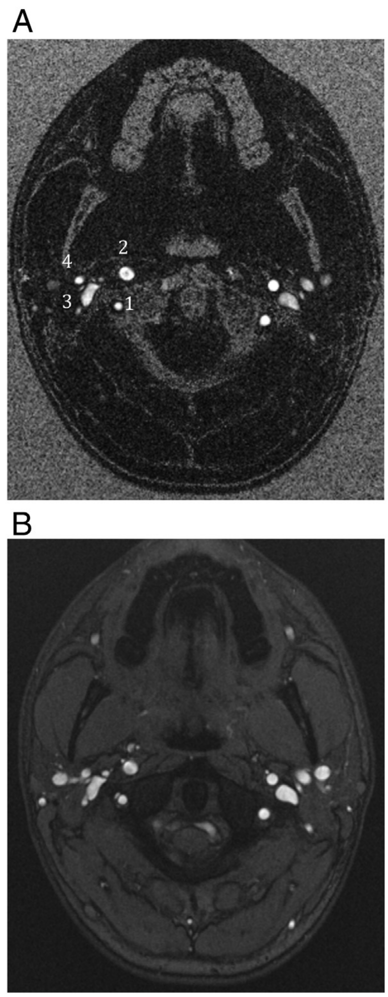

Fig 2. *A, An example phase-contrast image is presented, with regions of interest (ie, vascular cross sections) labeled. 1, Right VA; 2, right internal carotid artery; 3, right internal jugular vein; 4, external carotid artery. B, The corresponding magnitude image is shown.*

cycle. Owing to anatomical variations, occasional slices could only approximate orthogonality. To compensate for this, all image measurements were obtained using 2 anatomical sites and averaged to quantify flow and velocity. The first site was at the base of the odontoid process, and the second was approximately 1 cm above the tip of the dens. In 2 participants, where the low pair of VA images was too oblique, only the high slice approximating orthogonal orientation was used. Similarly, in another 2 participants with too much obliquity in the high pair of VA, only the low slice approximating the orthogonal orientation was used. According to Lotz et al,[46] vessel obliquity is tolerable to ±15°, above which will cause a deviation from the true flow. The 4 slices that were excluded were greater than 20° and thus not used.

Data capture was triggered by prospective gating using a peripheral pulse (MRI scanner–pulsed oximeter). The

Table 1. *Participant characteristics*

Participant	Age (y)	Height (cm)	Weight (kg)	Handedness
1	27	180.5	73.1	R
2	28	181.5	84.1	R
3	30	191.0	96.5	R
4	26	184.0	78.3	R
5	26	181.5	104.0	R
6	24	179.5	61.6	R
7	26	178.0	69.1	R
8	28	187.0	85.6	R
9	27	193.0	86.4	R
10	26	173.0	79.6	R
Mean ± SD	26.8 ± 1.6	182.9 ± 6.0	81.8 ± 12.5	R

image acquisition time for each flow measurement was approximately 1 minute 30 seconds depending on heart rate.[40] Flow analysis was performed using Segment v1.9 software[47] (Medviso, Lund, Sweden). Dynamic regions of interest were drawn on the left and right vertebral arteries to quantify mean, as well as peak, velocities, and flows. Data in the trigger window portion of the cardiac cycle were derived by spline interpolation using Matlab (Mathworks, Natick, MA). The final data set for a complete cardiac cycle, therefore, contained measurements from all the cardiac cycles that elapsed during the scan time. A typical phase-contrast image is presented in Figure 2, with regions of interest (ie, vascular cross sections) labeled.

Randomization of the test maneuvers for each volunteer was established prospectively using a randomized table generator (GraphPad Software Inc, La Jolla, CA). At enrollment, participants were allocated a random test maneuver order based on next in sequence. Flow quantification was performed by an experienced analyst who remained blinded to the test maneuvers.

Descriptive statistics were calculated for all variables. Mean and SDs were calculated for VA blood velocity, flow, peak velocity, and peak flow for each of the head conditions and VA side. Differences between task maneuvers and VA flow and velocity were evaluated using a repeated-measures analysis of variance with factors of head position and VA side, and a level of significance was set at .05, using R-project version 2.12.1 (R Development Core Team, 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/).

Results

Ten male participants aged 24 to 30 years (mean [SD], 26.8 [1.6] years) participated in this study. Mean (SD) height was 182.9 (6.0) cm, mean (SD) weight was 81.8 (12.5) kg, and all participants were right-hand dominant (Table 1). Each participant's data were collected in 1 session lasting

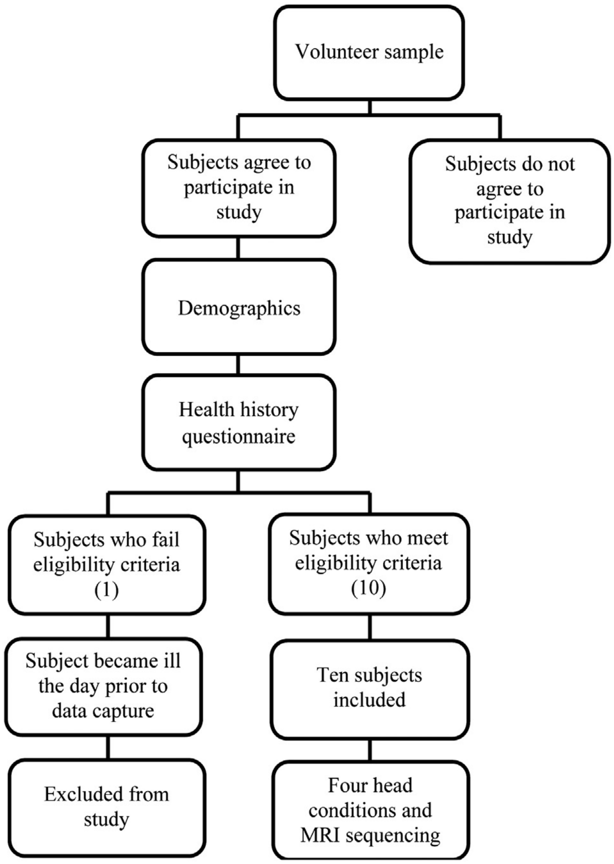

Fig 3. *A timeline scheme demonstrating participant flow from initial contact to study inclusion.*

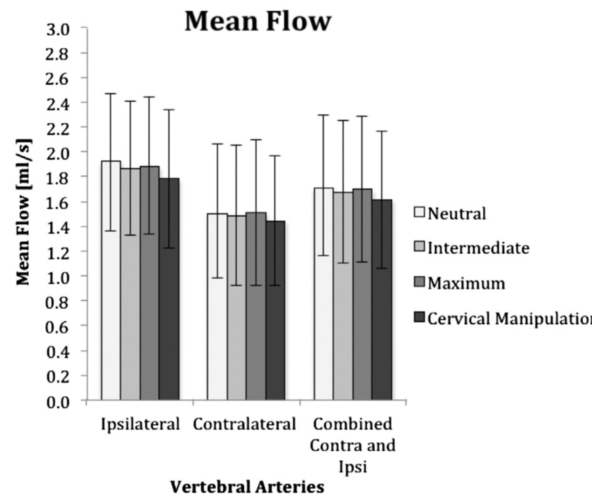

Fig 4. *Vertebral artery mean flow (in milliliters per second) at the C1-2 spinal level as determined by phase-contrast MRI for each of the 4 conditions with respect to the ipsilateral and contralateral vertebral arteries.*

approximately 2 hours. All 10 participants completed the full testing protocol including the 4 head conditions and MRI sequencing. Figure 3 depicts the timeline from initial contact to MRI testing. All reported blood flow measures are within the period of MRI data capture and assessment.

Preliminary estimates of test-retest repeatability demonstrated excellent agreement in phase-contrast data analysis, with measures ranging from 95% to 100% across the dependent variables over a 2-month time period.

The result of the analysis of variance suggests that there was a trend toward a difference in mean flow (P = .051) when the contralateral and ipsilateral vertebral arteries data were pooled for mean flow. However, based on the magnitude of the head condition responses (those observed effects to VA blood flow after the head conditions) vs their SDs, it is difficult to suggest any real trends (Fig 4).

The side-to-side difference between ipsilateral and contralateral VA velocities is shown in Figures 4 and 5. Although there appears to be a difference depicting a lower contralateral VA flow (Fig 4) and VA velocity (Fig 5) compared with the ipsilateral VA, this change was not significant for either velocities (P = .14) or flows (P = .19) throughout the conditions. There were no other interactions or trends toward a difference for any of the other blood flow or velocity variables.

The following is a descriptive representation of the findings. The phase-contrast MRI analysis of VA blood velocity measures is depicted in Table 2. Ipsilateral mean velocity was higher in all conditions compared with the contralateral side. The mean ipsilateral VA velocity demonstrated small decreases as head rotation increased. At neutral (0°), the mean velocity measured 16.7 (0.9) cm/s and slightly decreased at the intermediate position (45°) to 16.0 (1.6) cm/s. After maximum rotation (mean [SD], 69.7° [5.0°]), the ipsilateral mean velocity increased back to 16.7 (1.6) cm/s. After CSM, the mean velocity decreased to 16.1 (1.7) cm/s. The contralateral VA mean velocities also demonstrated small decreases as more rotation was applied. At neutral, VA velocity measured 15.5 (3.0) cm/s and decreased to 14.8 (2.7) cm/s after intermediate rotation and continued to decrease to 14.5 (3.2) cm/s after maximum rotation and 14.2 (2.7) cm/s after CSM. The phase-contrast MRI analysis of VA velocity is depicted in Figure 5.

The mean and peak ipsilateral VA flow were consistently higher than the contralateral side for all conditions. The difference between ipsilateral and contralateral mean and peak flow was small, equating to 0.4 mL/s in mean flow and 0.3 to 0.5 mL/s in peak flow for all conditions. There were also very minor changes noted throughout all head positions for both the ipsilateral and contralateral VA for mean and peak flow. The change between all conditions was very small, measuring 0.1 mL/s or less for both mean and peak flow. The phase-contrast MRI analysis of VA blood flow is depicted in Figure 4.

The 10-point analogue scale on the quality of the CSM rendered from the participant and clinician's perspectives revealed minor changes in mean values between the

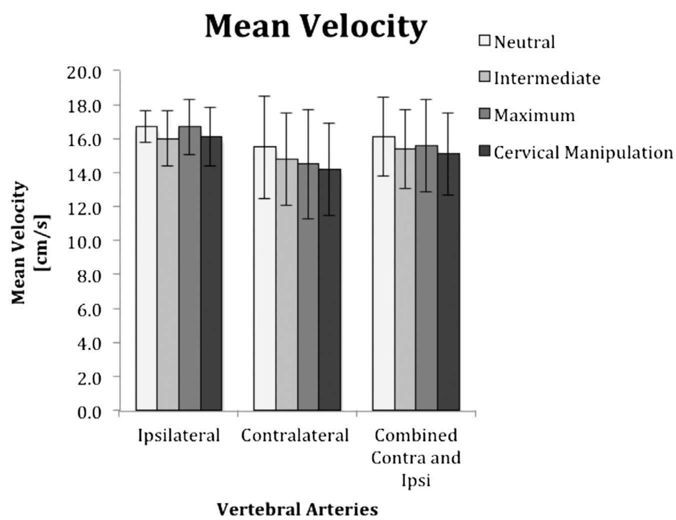

Fig 5. *Vertebral artery mean velocity (in centimeters per second) at the C1-2 spinal level for each of the 4 conditions with respect to the ipsilateral and contralateral vertebral arteries as determined by phase-contrast MRI.*

clinician and participant for most of the word descriptors "fast" (8.5 ± 0.9 vs 8.7 ± 0.8), "comfort" (8.6 ± 0.8 vs 9.2 ± 0.6), "confidence" (8.7 ± 0.7 vs 9.1 ± 0.6), and "precise" (8.6 ± 1.1 vs 9.0 ± 0.9). The largest difference was observed in the "force" category where the clinician's perspective on amount of force applied was greater than the receiving participant's perspective (7.6 ± 1.2 vs 4.4 ± 2.2) (Table 3).

No adverse events occurred during the study period, and none were reported after the study period.

Discussion

This study contributes to a limited body of knowledge regarding the vascular impacts of head position and cervical manipulation and is the first to obtain direct flow and velocity data across a range of mechanical challenges to the cervical spine.

No significant differences were observed in either blood flow or blood velocity of the V3 VA segment after head rotation or from high-velocity, low-amplitude manipulation procedure in healthy young male participants. A trend toward significance in mean flow was noted only when contralateral and ipsilateral VA data were pooled (P = .051). Based on the variation in magnitude of response from different head positions, it is difficult to suggest any trend. Ho et al[40] state that physiologic variation, vessel anatomical variation, respiratory vessel movement, inconsistent definition of the vessel boundary, and the general condition of participant can result in MRI phase-contrast measurement error. Poor resolution of vessel edge and partial volume effects are other sources of random noise in flow quantification.[40,48] Standardization of technique, with an imaging modality known to be accurate, reliable, and reproducible,[40,49] was used to minimize these error sources.

The results regarding the quality of the CSM from the participant and clinician's perspectives have similarities to what is reported in the literature. Rating of force values was within the ranges of force from clinically relevant high-velocity, low-amplitude procedures[43] performed by trained operators. That the operator in this work reported lower force levels likely reflects the difference in experience between the participants, who themselves are familiar with and in training for these procedures and the operator with more than 30 years' experience. Two studies, Descarreaux et al,[50] and Triano et al[51] examining the maturation of skill in delivery of manipulation procedures, note that more experienced operators provide higher force rates (speed) in trade-off for lower-force amplitudes.[50,51]

Table 2. *Contralateral and ipsilateral VA mean velocity, mean flow, peak velocity, and peak flow at the level of C1-2 for each of the 4 conditions*

Conditions	Ipsilateral	Contralateral	Combined
Velocity (cm/s), mean (SD)			
Neutral	16.7 (0.9)	15.5 (3.0)	16.1 (2.3)
Intermediate	16.0 (1.6)	14.8 (2.7)	15.4 (2.3)
Maximum	16.7 (1.6)	14.5 (3.2)	15.6 (2.7)
Cervical manipulation	16.1 (1.7)	14.2 (2.7)	15.1 (2.4)
Peak velocity (cm/s), mean (SD)			
Neutral	19.1 (1.7)	18.5 (3.7)	18.8 (2.8)
Intermediate	19.3 (1.6)	18.6 (3.3)	18.9 (2.6)
Maximum	19.4 (2.0)	17.0 (3.6)	18.2 (3.0)
Cervical manipulation	18.7 (1.7)	16.9 (3.1)	17.8 (2.6)
Flow (mL/s), mean (SD)			
Neutral	1.9 (0.5)	1.5 (0.6)	1.7 (0.6)
Intermediate	1.9 (0.5)	1.5 (0.6)	1.7 (0.6)
Maximum	1.9 (0.6)	1.5 (0.6)	1.7 (0.6)
Cervical manipulation	1.8 (0.6)	1.4 (0.5)	1.6 (0.6)
Peak flow (mL/s), mean (SD)			
Neutral	2.2 (0.7)	1.7 (0.6)	2.0 (0.7)
Intermediate	2.1 (0.6)	1.8 (0.6)	1.9 (0.6)
Maximum	2.1 (0.6)	1.8 (0.7)	2.0 (0.7)
Cervical manipulation	2.1 (0.6)	1.7 (0.6)	1.9 (0.6)

Table 3. *Results of the analogue scale on the quality of the CSM rendered from the participants' and clinician perspectives*

Word descriptors	Clinician, mean (SD)	Participant (mean, SD)
Fast	8.5 (0.9)	8.7 (0.8)
Force	7.6 (1.2)	4.4 (2.2)
Comfort	8.6 (0.8)	9.2 (0.6)
Confidence	8.7 (0.7)	9.1 (0.6)
Precise	8.6 (1.1)	9.0 (0.9)

The slight reduction of contralateral mean velocities with cervical rotation observed in this study is consistent with the findings in a recent meta-analysis of Doppler US studies of VA response associated with cervical spine rotation in adults.[17] Eight of the 9 studies examined found a decrease in contralateral mean blood velocity (in centimeters per second). Furthermore, only 2 trials have examined the effects of CSM on human VA blood flow.[18,28] Licht et al.[18] examined peak velocity in the VA after CSM on 20 students with biomechanical cervical spine dysfunction in a randomized controlled trial using Doppler ultrasound. Similar to the MRI data reported here, there was no significant change in peak velocity between the CSM group and a control sample. In another randomized controlled trial color-coded duplex sonography, Licht and colleagues[28] found no change in VA blood flow with change in head position or after CSM on blood flow.

Considering the trend of a small reduction in flow, the most relevant question is whether such differences are clinically meaningful. Consistent with the hypothesis of potential arterial stenosis secondary to CSM and head rotation, guidance can be found in the literature with respect to diagnosis of stenoses. A diameter reduction of 50% (75% area reduction) is often referred to as "hemodynamically significant" stenosis.[52] Staub et al[53] found "nonsignificant" stenosis for the renal artery as being narrowing less than 50% using arteriography color-coded duplex sonography. Peak arterial velocities for more than 50% stenosis were 200 cm/s. The authors report diagnostic sensitivity of 92% and specificity of 81%. Similarly, for the VA, more than 50% stenosis is associated with greater than 108-cm/s peak flow (sensitivity, 96%; specificity, 89%) and an end-diastolic flow of 36 cm/s.[54] Using these kinds of reference points, Licht et al.[18] calculated that changes in peak velocity of greater than 25% from baseline are considered clinically relevant. Furthermore, Seidel et al[55] state that values well below 200 mL/min are within the reference range for net VA flow volume and consider flow volume of less than approximately 100 mL/min an indication of low VA flow.

For the data reported in the present work, arterial flows were never more than half of the end-diastolic flows seen in the reports of confirmed stenosis by Yurdakul and Tola[54] and are fully within the reference range after all head positions and CSM. The largest changes were observed during contralateral rotation, whereby the VA velocity after CSM was 8% lower than the neutral position and 9% lower than the intermediate position for peak velocity measures. When examining VA flows, the largest change was 7%, which was observed in the contralateral VA after CSM. These relative blood flow changes are small and, according to Licht et al, are not considered clinically relevant. Seidel et al[55] measured normal flow volumes in healthy participants, finding a wide variation. Although not significantly different, mean (SD) volumes (77.2 [29.8] mL/min) were lower on the right and higher on the left (105.3 [46.4] mL/min). Both the ipsilateral flow at 112.5 mL/min and the contralateral flow at 88.5 mL/min are within the reference ranges published by Seidel et al.

Vertebrobasilar artery stroke can occur for a number of reasons. In the case of trivial traumatic events, the theoretical focus is on mechanical force associated with head movement induces irritation or damage to the intimal lining and resulting in either vasospasm or tearing of the VA, altering blood flow.[56] The popular conjecture that head rotation, including CSM, may result in stretching, and compression of the VA leading to a decrease in the cross-sectional area of the vessel[56] was not directly tested in our study. No direct arteriography was performed. Considering the kinematics of the cervical spine during rotation, it seems plausible that there may be mechanical changes to the VA. However, in cadaveric studies, Symons et al[57] and Wuest et al[58] measured the axial forces sustained by the VAs during range of motion, injury testing, and various CSMs using paired piezoelectric crystals sewn within the arterial wall. Cervical spinal manipulation produced lower strain values than those associated with physiologic neck rotation. In addition, Austin et al[59] found that cadaveric rabbit arterial tissue of similar size, structure, and mechanical properties to the human VA does not incur microstructural damage when exposed to 1000 strain cycles of magnitude and speed corresponding to the maximal values observed in the human cadaveric VA during CSM to the neck.

Limitations

There are several limitations to the study methods. The sample size was small and therefore limits the generalizability conclusions and the number of parameters that can be statistically tested. Random sequencing of head positions, intended to control for any sequencing effects, requires reliance on the existing literature for understanding of neutral, resting flows. The time interval between head condition application and arterial flow quantification was potentially large enough that any transient effect of head movement may have been missed. In addition, postmaneuver analysis makes comparison with other real-time studies difficult and can therefore only describe postprocedural effects rather than effects that occur during a specific maneuver. Although flow quantification demonstrates good test retest comparison, intraobserver variation was not directly analyzed. Magnetic resonance imaging is identified as the most accurate quantification of flow in the literature; however, physiologic variation, vessel anatomical variation, respiratory vessel movement, inconsistent definition of the vessel boundary, and the general condition of participant can result in technical difficulties and variation in flow measures. Cerebral circulation is not limited to the VA contributions but includes flow from the carotid arteries, which were not measured. Finally, peripheral gating for image acquisition combined with the inability to guarantee precisely orthogonal cross sections may underestimate arterial flows.

Future Studies

Evaluation of sample populations deemed of higher risk than healthy adult men may be warranted; however, based on the literature, such criteria are unclear.

Conclusion

Phase-contrast MRI measure of blood velocity and flow through the V3 segment of the VA showed no significant changes in association with either head rotations or chiropractic CSM procedure. No evidence of cerebrovascular hemodynamic effects as a result of mechanical interactions with the VA during head motions was identified.

Practical Application

- This study investigates the cerebrovascular hemodynamic consequences of cervical spine positions, including rotation and manipulation using MRI technology on the VA.
- There were no significant changes after various head positions and manipulation on blood flow and velocity in the vertebral arteries of healthy young male adults.
- This study contributes to a limited body of knowledge regarding the vascular impacts of head position and cervical manipulation and is the first to obtain direct flow and velocity data across a range of mechanical challenges to the cervical spine.

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Funding Sources and Potential Conflicts of Interest

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Contributorship Information

Concept development (provided idea for the research): JQ, JT, GW.
Design (planned the methods to generate the results): JQ, JT, MN, GW.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): JQ, JT, GW.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): JQ, JT, MN.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): JQ, JT, GW.
Literature search (performed the literature search): JQ, GW.
Writing (responsible for writing a substantive part of the manuscript): JQ, JT.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): JQ, MN, GW.

References

1. Public Health Agency of Canada. Tracking Heart Disease & Stroke in Canada [Internet]. Ottawa: Public Health Agency of Canada; 92p. [cited 2011 April 25]. Ottawa; 2009 p. 1–118. Available from: www.phac-aspc.gc.ca/publicat/2009/cvd-avc/pdf/cvd-avs-2009-eng.pdf.
2. Baracchini C, Tonello S, Meneghetti G, Ballotta E. Neurosonographic monitoring of 105 spontaneous cervical artery dissections: a prospective study. Neurology 2010;75:1864-70.
3. Baumgartner RW, Arnold M, Baumgartner I, et al. Carotid dissection with and without ischemic events: local symptoms and cerebral artery findings. Neurology 2001;57:827-32.

4. Debette S, Leys D. Cervical-artery dissections: predisposing factors, diagnosis, and outcome. Lancet Neurol 2009;8: 668-78.
5. Rubinstein SM, Haldeman S, Van Tulder MW. An etiologic model to help explain the pathogenesis of cervical artery dissection: implications for cervical manipulation. J Manipulative Physiol Ther 2006;29:336-8.
6. Haneline MT, Lewkovich GN. An analysis of the etiology of cervical artery dissections: 1994 to 2003. J Manipulative Physiol Ther 2005;28:617-22.
7. Sturzenegger M, Mattle HP, Rivoir A, Rihs F, Schmid C. Ultrasound findings in spontaneous extracranial vertebral artery dissection. Stroke 1993;24:1910-21.
8. Sengelhoff C, Nebelsieck J, Nassenstein I, et al. Neurosonographical follow-up in patients with spontaneous cervical artery dissection. Neurol Res 2008;30:687-9.
9. Weintraub M, Khoury A. Critical neck position as an independent risk factor for posterior circulation. J Neuroimaging 1995;5:16-22.
10. Haynes M. Vertebral arteries and neck rotation: Doppler velocimeter and duplex results compared. Ultrasound Med Biol 2000;26:57-62.
11. Haynes MJ. Doppler studies comparing the effects of cervical rotation and lateral flexion on vertebral artery blood flow. J Manipulative Physiol Ther 1996;119:378-84.
12. Thiel H, Wallace K, Donat J, Yong-Hing K. Effect of various head and neck positions on vertebral artery blood flow. Clin Biomech 1994;9:105-10.
13. Mitchell JA. Changes in vertebral artery blood flow following normal rotation of the cervical spine. J Manipulative Physiol Ther 2003;26:347-51.
14. Mitchell J, Keene D, Dyson C, Harvey L, Pruvey C, Phillips R. Is cervical spine rotation, as used in the standard vertebrobasilar insufficiency test, associated with a measureable change in intracranial vertebral artery blood flow? Man Ther 2004;9:220-7 Available from: http://www.ncbi.nlm.nih.gov/pubmed/15522647.
15. Mitchell J, Kramschuster K. Real-time ultrasound measurements of changes in suboccipital vertebral artery diameter and blood flow velocity associated with cervical spine rotation. Physiother Res Int 2008;13:241-54.
16. Kawchuk GN, Jhangri GS, Hurwitz EL, Wynd S, Haldeman S, Hill MD. The relation between the spatial distribution of vertebral artery compromise and exposure to cervical manipulation. J Neurol 2008;255:371-7.
17. Mitchell J. Vertebral artery blood flow velocity changes associated with cervical spine rotation: a meta-analysis of the evidence with implications for professional practice. J Man Manip Ther 2009;17:46-57.
18. Licht P, Christensen H, Højgaard P, Marving J. Vertebral artery flow and spinal manipulation: a randomized, controlled and observer-blinded study. J Manipulative Physiol Ther 1998;21:141–4. A.
19. Bronfort G, Haas M, Evans R, Leininger B, Triano J. Effectiveness of manual therapies: the UK evidence report. Chiropr Osteopath 2010;18:3.
20. Bronfort G, Haas M, Evans RL, Bouter LM. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: a systematic review and best evidence synthesis. Spine 2004;4:335-56.
21. Cassidy D, Boyle E, Cote P, et al. Risk of vertebrobasilar stroke and chiropractic care: results of a population based case control and case-crossover study. Spine 2008;33:176-83.
22. Gross A, Miller J, D'Sylva J, et al. Manipulation or mobilisation for neck pain: a Cochrane review. Man Ther 2010;15:315-33.
23. Hurwitz EL. Epidemiology: spinal manipulation utilization. J Electromyogr Kinesiol 2012;22:648-54.
24. Hurwitz EL, Carragee EJ, Van der Velde G, et al. Treatment of neck pain: noninvasive interventions: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. J Manipulative Physiol Ther 2009; 32(2 Suppl):S141-75.
25. Hurwitz EL, Morgenstern H, Harber P, Kominski GF, Yu F, Adams AH. A randomized trial of chiropractic manipulation and mobilization for patients with neck pain: clinical outcomes from the UCLA neck-pain study. Am J Public Health 2002;92:1634-41.
26. Boyle E, Grier AR, Cassidy JD. Examining vertebrobasilar artery stroke in two Canadian provinces. J Manipulative Physiol Ther 2008;32:194-200.
27. Licht PB, Christensen HW, Svendensen P, Høilund-Carlsen PF. Vertebral artery flow and cervical manipulation: an experimental study. J Manipulative Physiol Ther 1999;22: 431-5.
28. Licht PB, Christensen HW, Høilund-Carlsen PF. Vertebral artery volume flow in human beings. J Manipulative Physiol Ther 1999;22:363-7.
29. Dittrich R, Dziewas R, Ritter M, et al. Negative ultrasound findings in patients with cervical artery dissection. Negative ultrasound in CAD J Neurol 2006;253:424-33.
30. Dittrich R, Ritter MA, Ringelstein EB. Ultrasound in spontaneous cervical artery dissection. Perspectives in Medicine 2012;1:250-4.
31. Haynes MJ, Milne N. Color duplex sonographic findings in human vertebral arteries during cervical rotation. J Clin Ultrasound 2001;29:14-24.
32. Visser K, Hunink MGM. Peripheral arterial disease: gadolonium-enhanced MR angiography versus color-guided duplex US—a meta-analysis. Radiology 2000;216:67-77.
33. Stalder AF, Russe MF, Frydrychowicz A, Bock J, Hennig J, Markl M. Quantitative 2D and 3D phase contrast MRI: optimized analysis of blood flow and vessel wall parameters. Magn Reson Med 2008;60:1218-31.
34. Bendick PJ, Jackson VP. Evaluation of the vertebral arteries with duplex sonography. J Vasc Surg 1986;3:523-30.
35. Oktar SO, Yücel C, Karaosmanoglu D, et al. Blood-flow volume quantification in internal carotid and vertebral arteries: comparison of 3 different ultrasound techniques with phase-contrast MR imaging. Am J Neuroradiol 2006;27:363-9.
36. Alayon A, McKinney W. Normal vertebral artery hemodynamics and pathology. Vascular ultrasound of the neck. Philadelphia: Lippincott Williams & Wilkins; 2001. p. 107-19.
37. Bassi P, Lattuada P, Gomitoni A. Cervical cerebral artery dissection: a multicenter prospective study (preliminary report). Neurol Sci 2003:4-7.
38. Nebelsieck J, Sengelhoff C, Nassenstein I, et al. Sensitivity of neurovascular ultrasound for the detection of spontaneous cervical artery dissection. J Clin Neurosci 2009;16:79-82.
39. Schievink W. Spontaneous dissection of the carotid and vertebral arteries. N Engl J Med 2001;344:898-906.
40. Ho S, Chan Y, Yeung D, Metreweli C. Blood flow volume quantification of cerebral ischemia: comparison of three noninvasive imaging techniques of carotid and vertebral arteries. Imaging 2002:551-6.
41. Selvadurai HC, Allen J, Sachinwalla T, Macauley J, Blimkie CJ, Van Asperen PP. Muscle function and resting energy expenditure in female athletes with cystic fibrosis. Am J Respir Crit Care Med 2003;168:1476-80.
42. Triano JJ, Schultz A. Motions of the head and thorax during neck manipulations. J Manipulative Physiol Ther 1994;17: 573-83.

43. Cohen E, Triano JJ, McGregor M, Papakyriakou M. Biomechanical performance of spinal manipulation therapy by newly trained vs. practicing providers: does experience transfer to unfamiliar procedures? J Manipulative Physiol Ther 1995;18:347-52.
44. Triano J, Rogers C, Combs S, Potts D, Sorrels K. Developing skilled performance of lumbar spine manipulation. J Manipulative Physiol Ther 2002;25:353-61.
45. Triano J, Rogers C, Combs S, Potts D, Sorrels K. Quantitative feedback versus standard training for cervical and thoracic manipulation. J Manipulative Physiol Ther 2003; 26:131-8.
46. Lotz J, Meier C, Leppert A, Galanski M. Measurement with imaging: basic facts and implementation 1. Radiographics 2002;22:651-71.
47. Heiberg E, Sjögren J, Ugander M, Carlsson M, Engblom H, Arheden H. Design and validation of segment—freely available software for cardiovascular image analysis. BMC Med Imaging 2010:1-13.
48. Andersen A, Kirsch J. Analysis of noise in phase contrast imaging. Med Phys 1996;23:857-69.
49. Caroff J, Bière L, Trebuchet G, et al. Applications of phase-contrast velocimetry sequences in cardiovascular imaging. Diagn Interv Imaging 2012;93:159-70.
50. Descarreaux M, Dugas C. Learning spinal manipulation skills: assessment of biomechanical parameters in a 5-year longitudinal study. J Manipulative Physiol Ther 2010;33: 226-30.
51. Triano JJ, Gissler T, Forgie M, Milwid D. Maturation in rate of high-velocity, low-amplitude force development. J Manipulative Physiol Ther 2011;34:173-80.
52. Burns P. Hemodynamics. In: Taylor K, Burns P, Wells P, editors. Clinical applications of Doppler ultrasound. 2nd ed. New York, NY: Raven Press; 1995. p. 35-53.
53. Staub D, Canevascini R, Huegli R, et al. Best duplex-sonographic criteria for the assessment of renal artery stenosis—correlation with intra-arterial pressure gradient. Ultraschall Med 2007;28: 45-51.
54. Yurdakul M, Tola M. Doppler criteria for identifying proximal vertebral artery stenosis of 50% of more. J Ultrasound Med 2011;30:163-8.
55. Seidel E, Eicke B, Tettenborn B, Krummenauer F. Reference values for vertebral artery flow volume by duplex sonography in young and elderly adults. Stroke 1999;30:2692-6.
56. Mitchell J. Is mechanical deformation of the suboccipital vertebral artery during cervical spine rotation responsible for vertebrobasilar insufficiency? Physiother Res Int 2008;13:53-66.
57. Symons BP, Leonard T, Herzog W. Internal forces sustained by the vertebral artery during spinal manipulative therapy. J Manipulative Physiol Ther 2002;25:504-10.
58. Wuest S, Symons B, Leonard T, Herzog W. Preliminary report: biomechanics of vertebral artery segments C1-C6 during cervical spinal manipulation. J Manipulative Physiol Ther 2010;33:273-8.
59. Austin N, DiFrancesco LM, Herzog W. Microstructural damage in arterial tissue exposed to repeated tensile strains. J Manipulative Physiol Ther 2010;33:14-9.