Test-Retest Reliability of Measuring the Vertebral Arterial Blood Flow Velocity in People With Cervicogenic Dizziness

Gary L. Shum, PhD,[a] Sally Cinnamond, MSc,[a] Alan D. Hough, PhD,[a] Richard Craven, BSc,[b] and Wayne Whittingham, PhD[c]

Abstract

Objectives: The purpose of this study was to determine the within-session and between-sessions reliability of measuring the vertebral artery blood flow velocities in people with cervicogenic dizziness using Doppler ultrasound at both upper and lower cervical levels.

Methods: Outcome measures were taken on 2 occasions 3 weeks apart with no active treatment provided in between the assessments on 12 participants. Pulsed-wave Doppler ultrasound was used to quantify time-averaged mean velocities through the vertebral artery at upper cervical (C0-1) and lower cervical vertebrae (C5-6). The clinical outcome measures were also recorded in people with cervicogenic dizziness. The intraclass correlation coefficient (ICC) was used to determine the within-session and between-session repeatability. Paired *t* test was used to determine the differences in the time-averaged mean velocities of blood flow at the same site of the vertebral artery and the clinical outcome measures in 2 sessions 3 weeks apart.

Results: In people with cervicogenic dizziness, there was no significant change in both clinical outcome measures and the time-averaged mean velocities when the patients were measured 3 weeks apart ($P > .05$). This study identified good within-session (ICC: 0.903-0.967) and between-session (ICC: 0.922-0.984) repeatability in measuring the vertical blood flow velocities in patients with cervicogenic dizziness when the clinical outcome measures were unchanged.

Conclusions: This study supports the use of Doppler ultrasound to identify changes in mean vertebral arterial blood flow velocities before and after intervention in people with cervicogenic dizziness in future studies. (J Manipulative Physiol Ther 2017;xx:0-8)

Key Indexing Terms: *Doppler Ultrasound Imaging; Blood Flow Velocity; Vertebral Artery; Dizziness; Reliability*

Introduction

Dizziness is a common problem that can lead to disability and affect quality of life.[1-3] In some cases of dizziness the cause can be attributed to a pathologic condition or dysfunction of upper cervical vertebral segments.[4-7] This form of cervicogenic dizziness is characterized by symptoms of imbalance or spinning associated with neck pain, stiffness, or headache.[7]

It has been hypothesized that mechanical compression or stenosis of the vertebral artery could be one of the causes of cervicogenic dizziness.[8,9] Mechanical compression, tension, dissection, or stenosis of 1 of both vertebral arteries as they pass through the cervical region may reduce blood flow and thus result in symptoms of dizziness. Poor head and neck posture and malalignment of the upper cervical spine are among the causes of the mechanical compromise that could result in decreased vertebrobasilar blood flow velocity and lead to dizziness.[8,9] However, no studies to date have investigated the test-retest reliability in measuring the vertebral artery blood flow velocity in patients with cervicogenic dizziness over time. It can be hypothesized that vertebral artery blood flow velocity would stay the same if the symptoms of cervicogenic dizziness stay the same. The results of this study provide evidence to support the use of Doppler ultrasound in

[a] Faculty of Sport & Health Sciences, Plymouth Marjon University, Plymouth, United Kingdom.
[b] Vascular Assessment Unit, Derriford Hospital, Plymouth, United Kingdom.
[c] Plymouth Chiropractic Clinic, Plymouth, United Kingdom.
Corresponding author: Gary L. Shum, PhD, Faculty of Sport & Health Sciences, Plymouth Marjon University, Derriford Road, Plymouth PL6 8BH, United Kingdom.
(e-mail: *gshum@marjon.ac.uk*).
Paper submitted January 15, 2015; in revised form October 19, 2016; accepted October 19, 2016.
0161-4754

http://dx.doi.org/10.1016/j.jmpt.2017.02.005

investigating the role of vertebral arteries in management of cervicogenic dizziness in future studies.

Color duplex/Doppler ultrasound is considered to provide a valid[10] and reliable noninvasive measurement of vertebral arterial blood flow velcoity.[11-15] There are several studies reporting test-retest reliability of spectral Doppler ultrasound measures of vertebral artery blood flow. Schöning and Scheel[16] reported same-day repeat measure correlation coefficients in excess of 0.9 in measuring the cerebral time-averaged flow velocity and blood flow volume. Johnson et al[17] reported a good same-session test-retest (intraobserver) intraclass correlation coefficient (ICC) in the range of 0.80 to 0.94 for measures taken in left and right vertebral arteries velocities at the upper and lower cervical levels in asymptomatic participants. Previous works[14,17] suggest that it would be feasible to measure the vertebral blood flow characteristics at the lower cervical level (C5-6) and atlantooccipital (C0-1) level when the researchers adhere to protocol by taking account of potential confounding human factors, such as consistency of gain settings, Doppler angle, and stabilization of the ultrasound probe,[18] and possible habituation effects.[16]

There is evidence that Doppler ultrasound measures of vertebral artery blood flow may be sufficiently responsive to detect changes in cervical rotations[13] or after intervention.[19] It has been reported that a decrease in vertebral artery blood flow could be identified by Doppler ultrasound at both upper and lower cervical levels during end-range cervical rotation in asymptomatic participants.[12,20,21] This indicated that Doppler ultrasound would be able to detect changes in the vertebral arterial blood flow velocities decreased when the vertebral arteries are under stress from compression or stretching. Doppler ultrasound has also been used to detect improvement in vertebral arterial blood flow velocities in patients with vertebrobasilar artery insufficiency before and after medical intervention.[19,22] However, no studies have investigated upper and lower vertebral blood flow velocities in people with cervical dizziness. Consequently, it is unknown if there would be significant changes in vertebral artery blood flow velocities at the upper and lower cervical spine if clinical symptoms remain unchanged over a 3-week period in people with cervicogenic dizziness.

The aims of this study were to determine the within-session and between-sessions reliability of measuring the vertebral artery blood flow velocities in people with cervicogenic dizziness using Doppler ultrasound at both upper and lower cervical levels. It is hypothesized that no significant changes would occur in the vertebral artery velocities if there are no significant changes in the clinical symptoms in people with cervicogenic dizziness. The results of this study provide a basis to investigate the role of upper and lower vertebral arterial blood flow velocities and to support the use of Doppler ultrasound in determining the effect of intervention on the blood flow velocities in the management of cervicogenic dizziness in further studies.

Table 1. *Baseline Characteristics of Participants*

Age, y	45.1 ± 9.2
Weight, kg	72.64 ± 10.80
Height, m	1.68 ± 0.07
Onset of symptoms, mo	94.0 ± 65.9
Sex	Male: 5; female: 7

Methods

Participants

The experimental protocol was approved by the Faculty Research Ethics Committee of Faculty of Health, Education and Society at Plymouth University in the United Kingdom, and informed consent for the study was obtained from all participants per the World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects (2008). The sample size was estimated with an effect size of 0.75, a power of 0.80, and a significance level of 0.05.[23] A sample size of 12 was deemed to be appropriate for this matched pair study design. Therefore, 12 participants with symptoms of dizziness and neck pain as their main complaint were recruited with the following inclusion criteria: dizziness described as imbalance or unsteadiness; dizziness related to either movements or positions of the cervical spine, or occurring with a stiff or painful neck; symptoms lasting at least 4 weeks; and 18 to 55 years of age.

Participants were excluded if they had previous history of stroke or any neurologic disorders; had received chiropractic care or physiotherapy within the past 4 weeks; were currently receiving treatment for dizziness or neck pain by other health care providers; had inflammatory joint disease, infection, tumor, or fracture of the spine or cranium, central vascular/neurologic condition suspected of causing neck pain and/or dizziness/vertigo, or other conditions contraindicating high-velocity, small-amplitude spinal manipulative therapy; had evidence of narcotic or other drug abuse; were party to an ongoing personal injury or workers' compensation case related to dizziness/vertigo or neck pain or currently seeking or receiving disability for dizziness/vertigo or neck pain.

The baseline characteristics of the participants are presented in Table 1.

Equipment and Procedures

Outcome measures were taken on 2 occasions 3 weeks apart with no active treatment provided in between the assessments. Both the Doppler ultrasound readings and clinical outcome measures were taken by the same examiner.

Pulsed-wave Doppler ultrasound (Model: MySonoU5, Medison Co., Ltd, Seoul, South Korea) was used to quantify laminar blood flow velocity through the vertebral artery at upper (C0-1) and lower cervical vertebrae (C5-6).[13,15] All blood flow measurements were taken in a quiet, dimmed

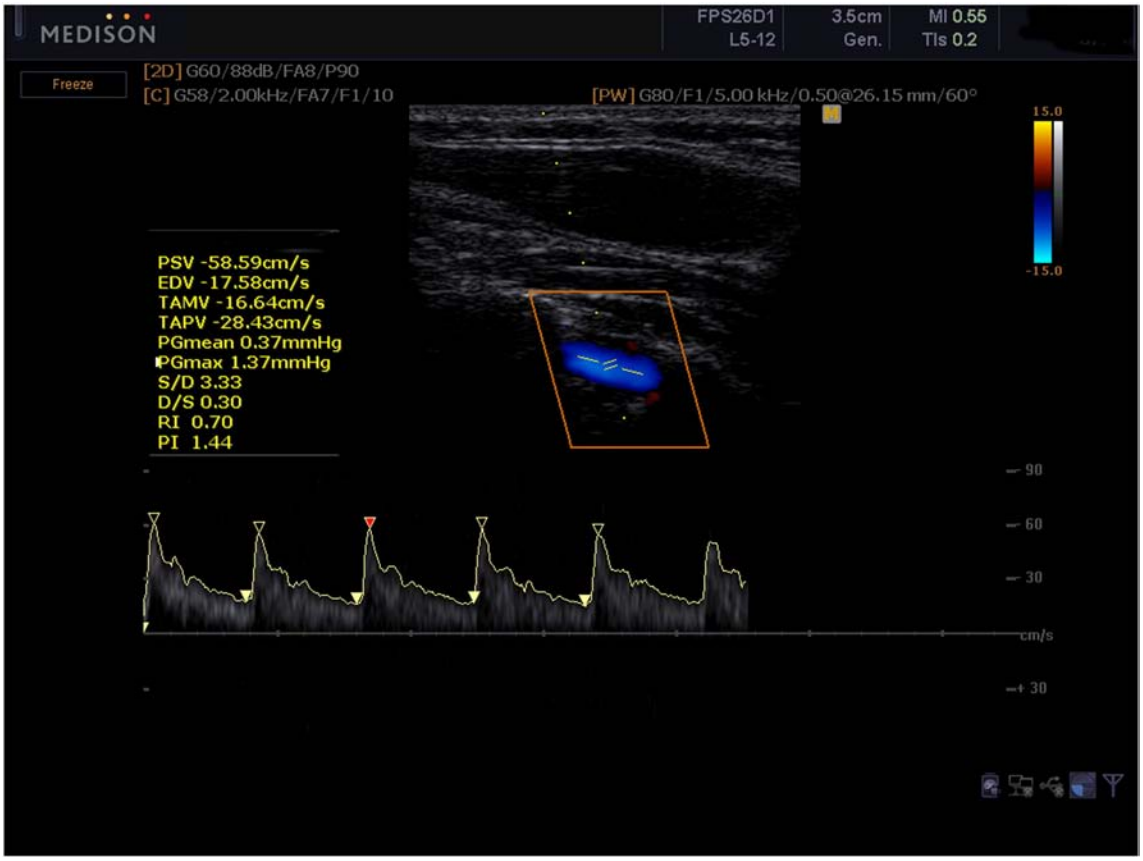

Fig 1. *Doppler ultrasound imaging measured at the lower cervical spine between fifth cervical vertebra and sixth cervical vertebra. Color version of figure available online.*

environment with the patient supine with head supported in neutral (no flexion or extension) and turned 10° to the contralateral side to allow ease of probe placement and optimal imaging of the artery at both upper and lower level. The measurements were taken in the order of lower right, lower left, upper right, upper left at the cervical spine for each participant. An initial image was taken at each site followed by a series of 3 measurements to ensure reliability of the measurement.[13,17,20] The Doppler sample gate was set at its smallest size and placed in the center of the vessel to standardize the signal received.

The lower vertebral artery measurement was taken at C5-6 level, which is typically the first entry level of the vertebral artery into the transverse foramen of the cervical spine (Fig 1).[17,20] The transducer was placed longitudinally at the anterolateral aspect of the neck and the probe shifted laterally until the cervical transverse processes were visualized and the entry of the vertebral artery into the transverse foramen identified. The vertebral artery was then tracked upward and measurement was taken between the transverse processes of the C5-6 (between fifth cervical vertebra (C5) and sixth cervical vertebra (C6). The upper level measurement was taken at atlantooccipital (C0-1) as the vertebral artery exited from the transverse foramen of atlas (C1) and passed on to the posterior arch of the atlas (Fig 2).[20] The probe was placed transversely below the mastoid process, posterior to the angle of the jaw.[20]

Once optimal imaging of the artery at both upper and lower cervical level had been acquired, offline analysis was carried by a separate researcher. The time-averaged mean velocities were determined with the angle of insonation adjusted at 60° (Figs 1 and 2). The order of the ultrasound imaging analysis was randomized, and the researcher was blinded to the order of the Doppler ultrasound imaging and clinical outcome measures of the participants.

Clinical Outcome Measures

Disability caused by dizziness was measured with the Dizziness Handicap Inventory. The Dizziness Handicap Inventory assesses the impact of dizziness on the functional, emotional, and physical aspects of everyday life.[24,25] The highest possible score is 100, indicating maximum self-perceived handicap. The Dizziness Handicap Inventory has been reported to be a highly reliable and responsive tool.[26,27] Significant correlations between Dizziness Handicap Inventory scores and specific objective measures of balance and gait have been reported.[28]

Fig 2. *Doppler ultrasound imaging measured at the upper cervical spine at atlantooccipital joint as the vertebral artery exited from the transverse foramen of atlas and passed on to the posterior arch of the atlas. Color version of figure available online.*

Dynamic balance in walking was measured by the Dynamic Gait Index.[29] Dynamic Gait Index assessed dynamic postural stability as functional gait according to 8 tasks with varying demands including walking at different speeds, walking with head movements, negotiating obstacles, turning, and ascending and descending stairs. Each item was rated on a 4-level ordinal scale, with a maximum score of 24.[29] The Dynamic Gait Index has been regularly used as a outcome measures in clinical trial for patients with balance problems.[30,31]

Severity of dizziness (an average level over the previous few days) was measured with a 10-cm visual analog scale. The visual analog scale has been used to measure dizziness in other clinical studies.[5]

Frequency of dizziness was measured on a 6-point rating scale (0 = no dizziness, 1 = dizziness less than once per month, 2 = 1-4 episodes of dizziness per month, 3 = 1-4 episodes of dizziness per week, 4 = dizziness once daily, 5 = dizziness more than once a day or constant).[32]

Active cervical range of motion was measured with a strap-on head goniometer consisting of an inclinometer dial for measuring flexion, and lateral flexion and a compass dial for measuring rotation (OB Myrin goniometer, OB Rehab, Solna, Sweden).[33]

Statistical Analysis

Statistical analysis was carried out with SPSS software (Version 19.0, IBM Corp., Armonk, NY). $ICC_{3,k}$ with a 95% confidence interval and standard error of measurement (SEM)[34] was calculated to determine intrarater reliability of the 3 repeat measures of time-averaged mean velocities of the upper and lower vertebral arterial blood flow in each session.

Paired *t* test was used to determine the differences in the time-averaged mean velocities of blood flow at the same site of the vertebral artery and the clinical outcome measures in 2 sessions 3 weeks apart. Level of significance was set at 0.05. Post hoc power calculation was carried out to determine the type II error when no significant differences were identified in the outcome measures between the 2 sessions.

Results

Participant characteristics were presented in Table 1.

Table 2. *Within-Session Intraclass Correlation at the First Session*

	ICC of TAMV	95% CI	SEM
Right vertebral artery at C5/6	0.914	0.805-0.965	1.05
Left vertebral artery at C5/6	0.957	0.916-0.980	0.99
Right vertebral artery at C0/1	0.903	0.789-0.965	1.11
Left vertebral artery at C0/1	0.908	0.783-0.962	1.30

CI, confidence interval; *ICC,* intraclass coefficient; *SEM,* standard error of measurement; *TAMV,* time-averaged mean velocities.

Table 3. *Within-Session Intraclass Correlation at the Second Session (3 Wk Later)*

	ICC of TAMV	95% CI	SEM
Right vertebral artery at C5/6	0.930	0.864-0.967	0.98
Left vertebral artery at C5/6	0.965	0.933-0.984	0.85
Right vertebral artery at C0/1	0.967	0.936-0.984	0.63
Left vertebral artery at C0/1	0.937	0.878-0.970	1.18

CI, confidence interval; *ICC,* intraclass coefficient; *SEM,* standard error of measurement; *TAMV,* time-averaged mean velocities.

Table 4. *Intraclass Correlation Between the 2 Sessions (First Session vs Second Session)*

	ICC of TAMV	95% CI	SEM
Right vertebral artery at C5/6	0.984	0.944-0.995	0.46
Left vertebral artery at C5/6	0.974	0.911-0.993	0.75
Right vertebral artery at C0/1	0.968	0.889-0.991	0.63
Left vertebral artery at C0/1	0.922	0.871-0.959	1.25

CI, confidence interval; *ICC,* intraclass coefficient; *SEM,* standard error of measurement; *TAMV,* time-averaged mean velocities.

The mean $ICC_{3,k}$ for measuring the blood flow velocities in the vertebral artery at upper and lower cervical levels were highly repeatable within each session (Table 2 and 3) and between sessions (Table 4). All the ICC values were >0.900. The ICC ranges from 0.903 to 0.957 in the first session, 0.930 to 0.967 in the second session, and 0.922 to 0.984 between the 2 sessions 3 weeks apart.

Paired *t* tests revealed no significant statistical differences in both the time-averaged mean velocities and clinical outcome measures between the 2 assessment sessions 3 weeks apart ($P > .05$; Tables 5 and 6).

The clinical outcome measures suggested that patients with cervicogenic dizziness in this study were being affected significantly in balance and quality of life. There was a high pain level, severity of dizziness, and frequency of dizziness (Table 6). The mean score of 48.11 out of 100 of the Dizziness Handicap Inventory suggested that this group of patients with cervicogenic dizziness had moderate handicap[25] (Table 6).

Discussion

This is the first study to report on a method both to measure vertebral arterial blood flow velocity by Doppler ultrasound in patients with cervicogenic dizziness and to investigate its reliability over a 3-week period. The reliability of the described method was excellent within sessions and between sessions. The technique would be highly repeatable and sufficiently precise to support its use as a research tool and in clinical practice.[35]

Measuring vertebral arterial blood flow velocities at C0-1 and C5-6 could provide a clinically meaningful outcome measure to identify potential changes in mean blood flow ?tlsb=-0.2pt?>velocity before and after intervention in people with cervicogenic dizziness in future studies. If the clinical outcome of patients improved after an intervention, it would be valuable to see if changes occur in the time-averaged blood flow velocities because this would identify the role of vertebral artery blood flow in patients with cervicogenic dizziness.

Doppler ultrasound has been reported to be sensitive enough to detect changes in vertebral arterial blood flow parameters in patients with vertebrobasilar artery insufficiency before and after medical intervention.[19,22] In addition, Doppler ultrasound also has been used to identify blood flow changes following at the end range of motion of neck rotation in asymptomatic participants, which could potentially exert pressure on the vertebral artery and reduce the blood flow velocity.[12,20,21]

In patients with cervicogenic dizziness and moderate handicap, there was no significant change in both clinical outcome measures and the time-averaged mean velocities when the patients were measured 3 weeks apart ($P > .05$, Tables 5 and 6). A compromise post hoc power analysis was carried out to identify the statistical power[23,36] of the Doppler vertebral blood flow assessments, vertebral arterial blood flow. The statistical power was excellent, ranging from 88.59% to 99.99%, ruling out the chance of type II error (false-negative) (Table 5).

This study had excellent between-session repeatability (ICC: 0.922-0.984) in measuring the vertebral arterial blood flow velocities in patients with cervicogenic dizziness. The vertebral arterial blood flow is readily identifiable at the upper and lower cervical spine; the use of body landmarks and the real-time visualization of the entry of the vertebral artery to transverse foramen from the Doppler imaging as well as standardization of protocol described in the methodology ensured good repeatability.

Limitations and Future Studies

There were some individual variations in the blood flow velocities with quite a large standard deviation (Table 5). This may limit the use of Doppler ultrasound as a diagnostic tool in

Table 5. *Time-Averaged Mean Velocities of the 2 Sessions*

	TAMV (cm/s)			
	First Session	Second Session (3 Wk Later)	*P*	Power (%)
Right vertebral artery at C5/6	14.07 ± 3.57	14.28 ± 3.69	.431	88.59
Left vertebral artery at C5/6	12.51 ± 4.78	12.06 ± 4.57	.316	99.99
Right vertebral artery at C0/1	11.17 ± 3.58	10.93 ± 3.47	.500	94.83
Left vertebral artery at C0/1	13.73 ± 4.29	13.63 ± 4.69	.943	97.82

SD, standard deviation; *TAMV,* time-averaged mean velocities.
Values are presented as mean ± SD. Paired *t* test revealed no significant differences in the time-averaged mean velocities (cm/s) between 2 sessions 3 weeks apart.

Table 6. *Clinical Outcome Measures Between the 2 Sessions*

	First Session	Second Session (3 Wk Later)	*P*
Dizziness Handicap Inventory (max: 100)	48.11 ± 16.19	48.15 ± 15.33	.957
Dynamic Gait Index (max: 24)	21.69 ± 1.55	22.15 ± 1.46	.351
Visual analog scale of neck pain (max: 10)	7.31 ± 1.7	6.69 ± 1.65	.359
Visual analog scale of severity of dizziness (max: 10)	5.69 ± 1.75	5.84 ± 1.68	.165
Frequency of dizziness (max: 5)	3.85 ± 1.21	3.77 ± 1.42	.584
Neck range of motion (degrees)			
Flexion	38.08 ± 10.9	41.92 ± 9.9	.192
Extension	41.15 ± 9.61	42.69 ± 8.81	.165
Rotation at the more restricted side	53.85 ± 11.21	51.54 ± 9.21	.165
Rotation at the less restricted side	60.00 ± 10.41	56.92 ± 9.69	.431
Side flexion at the more restricted side	28.08 ± 6.63	30.00 ± 7.91	.175
Side flexion at the less restricted side	31.92 ± 6.30	30.38 ± 8.53	.264

Paired *t* test revealed no significant differences in the clinical outcome measures ($P > .05$).

assessing patients with cervicogenic dizziness. However, we have indicated that determination of time-averaged mean velocities from the Doppler ultrasound at the upper and lower vertebral arteries could be used for evaluation for within-participant pairwise comparison in clinical populations. In this study, one of the limitations is that the order of measuring was not randomized, which was to ensure the standardization of the procedures.

This is the first study to measure the blood flow velocities in patients with cervicogenic dizziness over a 3-week period. The Doppler ultrasound findings indicated a very good reliability and it corroborated with the clinical outcome measurements. Further research is planned to provide an intervention to improve symptoms in people with cervicogenic dizziness and investigate if blood flow changes occur when the clinical symptoms improve. This will improve our understanding of the role of vertebral artery involvement in cervicogenic dizziness.

Conclusion

This study provides a foundation for the use of Doppler ultrasound in the assessment of patients with cervicogenic dizziness. The repeatability of time-averaged mean velocities was excellent between measurements taken 3 weeks apart when there was no change in clinical outcome measures.

Funding Sources and Conflicts of Interest

This study was funded by Australian Spinal Research Foundation Research Grant LG2011-4. No conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): G.S., S.C., A.H., R.C., W.W.
Design (planned the methods to generate the results): G.S., S.C., A.H., R.C., W.W.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): G.S., S.C., A.H., R.C., W.W.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): G.S., S.C., A.H., R.C., W.W.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): G.S., S.C., A.H., R.C., W.W.
Literature search (performed the literature search): G.S., S.C., A.H., R.C., W.W.
Writing (responsible for writing a substantive part of the manuscript): G.S., S.C., A.H., R.C., W.W.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): G.S., S.C., A.H., R.C., W.W.

Practical Applications

- This study provides a foundation for the use of Doppler ultrasound in the assessment of patients with cervicogenic dizziness.
- The repeatability of time-averaged mean velocities was excellent between measurements taken 3 weeks apart when there was no change in clinical outcome measures.
- Measuring vertebral arterial blood flow velocities at C0-1 and C5-6 could provide a clinically meaningful outcome measure to identify potential changes in mean blood flow velocity before and after intervention in people with cervicogenic dizziness in future studies. If the clinical outcome of patients improved after an intervention, it would be valuable to see if changes occur in the time-averaged blood flow velocities because this would identify the role of vertebral artery blood flow in patients with cervicogenic dizziness.

References

1. Colledge NR, Barr-Hamilton RM, Lewis SJ, Sellar RJ, Wilson JA. Evaluation of investigations to diagnose the cause of dizziness in elderly people: a community based controlled study. *BMJ.* 1996;313(7060):788-792.
2. Furman JM, Whitney SL. Central causes of dizziness. *Phys Ther.* 2000;80(2):179-187.
3. Yardley L, Redfern MS. Psychological factors influencing recovery from balance disorders. *J Anxiety Disord.* 2001; 15(1-2):107-119.
4. Brandt T, Bronstein AM. Cervical vertigo. *J Neurol Neurosurg Psychiatry.* 2001;71(1):8-12.
5. Heikkila H, Johansson M, Wenngren BI. Effects of acupuncture, cervical manipulation and NSAID therapy on dizziness and impaired head repositioning of suspected cervical origin: a pilot study. *Man Ther.* 2000;5(3):151-157.
6. Reid SA, Rivett DA. Manual therapy treatment of cervicogenic dizziness: a systematic review. *Man Ther.* 2005;10(1):4-13.
7. Wrisley DM, Sparto PJ, Whitney SL, Furman JM. Cervicogenic dizziness: a review of diagnosis and treatment. *J Orthop Sports Phys Ther.* 2000;30(12):755-766.
8. Biesinger E. Vertigo caused by disorders of the cervical vertebral column. Diagnosis and treatment. *Adv Otorhinolaryngol.* 1988; 39:44-51.
9. Fitz-Ritson D. Assessment of cervicogenic vertigo. *J Manip Physiol Ther.* 1991;14(3):193-198.
10. Newell DW, Aaslid R. Transcranial Doppler. New York, NY: Lippincott Williams and Wilkins; 1991.
11. Creighton D, Kondratek M, Krauss J, Huijbregts P, Qu H. Ultrasound analysis of the vertebral artery during non-thrust cervical translatoric spinal manipulation. *J Man Manip Ther.* 2011;19(2):84-90.
12. 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 measurable change in intracranial vertebral artery blood flow? *Man Ther.* 2004;9(4): 220-227.
13. Mitchell J. Doppler insonation of vertebral artery blood flow changes associated with cervical spine rotation: Implications for manual therapists. *Physiother Theory Pract.* 2007;23(6): 303-313.
14. 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(1):46-57.
15. Haynes MJ. Vertebral arteries and neck rotation: Doppler velocimeter and duplex results compared. *Ultrasound Med Biol.* 2000;26(1):57-62.
16. Schöning M, Scheel P. Color duplex measurement of cerebral blood flow volume: intra- and interobserver reproducibility and habituation to serial measurements in normal subjects. *J Cereb Blood Flow Metab.* 1996;16(3):523-531.
17. Johnson C, Grant R, Dansie B, Taylor J, Spyropolous P. Measurement of blood flow in the vertebral artery using colour duplex Doppler ultrasound: establishment of the reliability of selected parameters. *Man Ther.* 2000;5(1): 21-29.
18. Lui EY, Steinman AH, Cobbold RS, Johnston KW. Human factors as a source of error in peak Doppler velocity measurement. *J Vasc Surg.* 2005;42(5):972-979.
19. Bozgeyik Z, Berilgen S, Ozdemir H, Tekatas A, Ogur E. Evaluation of the effects of sildenafil citrate (Viagra) on vertebral artery blood flow in patients with vertebro-basilar insufficiency. *Korean J Radiol.* 2008;9(6):477-480.
20. 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(4):241-254.
21. Refshauge KM. Rotation: a valid premanipulative dizziness test? Does it predict safe manipulation? *J Manip Physiol Ther.* 1994;17(1):15-19.
22. 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(2):105-110.
23. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods.* 2009;41(4):1149-1160.
24. Clendaniel RA. Outcome measures for assessment of treatment of the dizzy and balance disorder patient. *Otolaryngol Clin N Am.* 2000;33(3):519-533.
25. Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory. *Arch Otolaryngol Head Neck Surg.* 1990; 116(4):424-427.
26. Newman C, Jacobson G. Application of self-report scales in balance function handicap assessment and management. *Semin Hear.* 1993;14(4):363-375.
27. Enloe LJ, Shields RK. Evaluation of health-related quality of life in individuals with vestibular disease using disease-specific and general outcome measures. *Phys Ther.* 1997; 77(9):890-903.
28. Whitney SL, Wrisley DM, Brown KE, Furman JM. Is perception of handicap related to functional performance in

persons with vestibular dysfunction? *Otol Neurotol.* 2004; 25(2):139-143.
29. Wrisley DM, Walker ML, Echternach JL, Strasnick B. Reliability of the dynamic gait index in people with vestibular disorders. *Arch Phys Med Rehabil.* 2003;84(10):1528-1533.
30. Karapolat H, Celebisoy N, Kirazli Y, et al. Is vestibular rehabilitation as effective in bilateral vestibular dysfunction as in unilateral vestibular dysfunction? *Eur J Phys Rehabil Med.* 2014;50(6):657-663.
31. Smaerup M, Gronvall E, Larsen SB, Laessoe U, Henriksen JJ, Damsgaard EM. Computer-assisted training as a complement in rehabilitation of patients with chronic vestibular dizziness—a randomized controlled trial. *Arch Phys Med Rehabil.* 2015;96(3):395-401.
32. Karlberg M, Magnusson M, Eva-Maj M, Agneta M, Moritz U. Postural and symptomatic improvement after physiotherapy in patients with dizziness of suspected cervical origin. *Arch Phys Med Rehabil.* 1996;77(9):874-882.
33. Whittingham W, Nilsson N. Active range of motion in the cervical spine increases after spinal manipulation (toggle recoil). *J Manip Physiol Ther.* 2001;24(9):552-555.
34. Portney LG, Watkins MP. Foundations of Clinical Research: Applications to Practice. Hoboken, NJ: Pearson; 2009.
35. Kottner J, Audige L, Brorson S, et al. Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were proposed. *Int J Nurs Stud.* 2011;48(6):661-671.
36. Mayr S, Erdfelder E, Buchner A, Faul F. A short tutorial of GPower. *Tutor Quant Methods Psychol.* 2007;3(2):51-59.