PLYMOUTH
MARJON
UNIVERSITY

Title: Test-Retest Reliability of Measuring the Vertebral Arterial Blood Flow

Velocity in People With Cervicogenic Dizziness

Author(s): Shum, Gary L.; Cinnamond, Sally; Hough, Alan D.; Craven, Richard and

Whittingham, Wayne

Copyright, publisher and additional information:

Test-retest reliability of measuring the vertebral arterial blood flow velocity in people with cervicogenic dizziness.

Shum GL, Cinnamond S, Hough AD, Craven R and Whittingham W.

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 two occasions three weeks apart with no active treatment provided in between the assessments on twelve participants. Pulsed-wave Doppler ultrasound was used to quantify time average 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. Intraclass correlation coefficient was used to determine the within-session and between-session repeatability. Paired t-test was used to determine the differences in the time average mean velocities of blood flow at the same site of the vertebral artery and the clinical outcome measures in two sessions three weeks apart.

Results

In people with cervicogenic dizziness, there was no significant change in both clinical outcome measures and the time average mean velocities when the patients were measured three weeks apart (p > 0.05). This study demonstrated 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.

Key Words: Doppler Ultrasound Imaging, Blood flow Velocity, Vertebral Artery, Dizziness, Reliability.

1   Introduction

2   Dizziness is a common problem that can lead to disability and impact on quality of

3   life.[1-3] In some cases of dizziness the cause can be attributed to pathology or dysfunction of

4   upper cervical vertebral segments.[4-7] This form of cervicogenic dizziness is characterized by

5   symptoms of imbalance or spinning associated with neck pain, stiffness or headache.[7]

6   It has been hypothesised that mechanical compression or stenosis of the vertebral

7   artery could be one of the reasons leading to cervicogenic dizziness.[8,9] Mechanical

8   compression, tension, dissection, or stenosis of one of both vertebral arteries as they pass

9   through the cervical region may reduce blood flow and thus result in symptoms of dizziness.

10 Poor head and neck posture and mal-alignment of the upper cervical spine are among the

11 causes of the mechanical compromise that could result in decreased vertebrobasilar blood

12 flow velocity and lead to dizziness.[8,9] However, to date no studies have investigated the test

13 retest reliability in measuring the vertebral artery blood flow velocity in patients with

14 cervicogenic dizziness over a period of time. It can be hypothesised that vertebral artery

15 blood flow velocity would stay the same if the symptoms of cervicogenic dizziness stay the

16 same. The results of this study provide evidence to support the use of Doppler ultrasound in

17 investigating the role of vertebral arteries in management of cervicogenic dizziness in future

18 studies.

19 Colour duplex/Doppler ultrasound is considered to provide a valid[10] and reliable non-invasive

20 measurement of vertebral arterial blood flow velcoity.[11-15] There are several studies reporting

21 test-retest reliability of spectral Doppler ultrasound measures of vertebral artery blood flow.

22 Schoning and Scheel[16] reported same day repeat measure correlation coefficients in excess of

23 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 (intra-observer) intraclass correlation coefficient in the range of 0.80 -0.94 for measures taken in left and right vertebral arteries velocities at the upper and lower cervical levels in asymptomatic participants. Previous work[14,17] suggests that it would be feasible to measure the vertebral blood flow characteristics at the lower cervical level(C5-6) and atlanto-occipital (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 stabilisation 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 following 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 demonstrated 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 three week period in people with cervicogenic dizziness.

1   The aims of this study were to determine the within session and between sessions

2   reliability of measuring the vertebral artery blood flow velocities in people with cervicogenic

3   dizziness using Doppler ultrasound at both upper and lower cervical levels. It is hypothesized

4   that no significant changes would occur in the vertebral artery velocities if there are no

5   significant changes in the clinical symptoms in people with cervicogenic dizziness. The

6   results of this study provide a basis to investigate the role of upper and lower vertebral

7   arterial blood flow velocities and to support the use of Doppler ultrasound in determining the

8   effect of intervention on the blood flow velocities in the management of cervicogenic

9   dizziness in further studies.

1   **Methods**

2   *Participants*

3   The experimental protocol was approved by the Faculty Research Ethics Committee of

4   Faculty of Health, Education and Society, Plymouth University, United Kingdom and

5   informed consent for the study was obtained from all participants per the WORLD Medical

6   Association Declaration of Helsinki: Ethical principles for medical research involving human

7   subjects, 2008. The sample size was estimated with an effect size of 0.75, a power of 0.80

8   and a significance level of 0.05[23]. A sample size of twelve was deemed to be appropriate for

9   this matched pair study design. Therefore, twelve participants with symptoms of dizziness

10   and neck pain as their main complaint were recruited with the following inclusion criteria:

11   • Dizziness described as imbalance or unsteadiness.

12   • Dizziness related to either movements or positions of the cervical spine, or occurring

13   with a stiff or painful neck.

14   • Symptoms lasting for at least 4 weeks.

15   • 18-55 years of age.

16   Participants were excluded if they had:

17   • Previous history of stroke, or any neurological disorders.

18   • Chiropractic care or physiotherapy within the past 4 weeks.

19   • Currently receiving treatment for dizziness/neck pain by other healthcare providers.

20   • Presence of inflammatory joint disease, infection, tumour, or fracture of the spine or

21   cranium, central vascular/ neurologic condition suspected of causing neck pain and/or

22   dizziness/vertigo or other conditions contraindicating high-velocity, small-amplitude

23   spinal manipulative therapy.

1   • Evidence of narcotic or other drug abuse.

2   • An on-going personal injury or workers' compensation case related to

3   dizziness/vertigo or neck pain or currently seeking or receiving disability for

4   dizziness/vertigo or neck pain.

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

6

7   *Equipment and procedures*

8   Outcome measures were taken on two occasions three weeks apart with no active treatment

9   provided in between the assessments. Both the Doppler ultrasound readings and clinical

10   outcome measures were taken by the same examiner.

11   Pulsed-wave Doppler ultrasound (Model: MySonoU5, Medison Co., Ltd, Seoul, South

12   Korea) was used to quantify laminar blood flow velocity through the vertebral artery at upper

13   (C0-1) and lower cervical vertebrae (C5-6)[13,15]. All blood flow measurements were taken in a

14   quiet, dimmed environment with the patient supine with head supported in neutral (no flexion

15   or extension) and turned 10 degrees to the contralateral side to allow ease of probe placement

16   and optimal imaging of the artery at both upper and lower level. The measurements were

17   taken in the order of lower right, lower left, upper right, upper left at the cervical spine for

18   each participant. An initial image was taken at each site followed by a series of three

19   measurements to ensure reliability of the measurement.[13,17,20] The Doppler sample gate was

20   set at its smallest size and placed in the center of the vessel in order to standardize the signal

21   received.

22

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(Figure 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 visualised and the entry of the vertebral artery into the transverse foramen identified. The vertebral artery was then tracked upwards and the measurement 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 atlanto-occipital (C0-1) as the vertebral artery exited from the transverse foramen of atlas(C1) and passed onto the posterior arch of the atlas(Figure 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 have been acquired, off-line analysis was carried by a separate researcher. The time average mean velocities were determined with the angle of insonation adjusted at 60 degrees (Figures 1 and 2). The order of the ultrasound imaging analysis has been randomised 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 shown to be

1 a highly reliable and responsive tool.[26,27] Significant correlations between Dizziness

2 Handicap Inventory scores and specific objective measures of balance and gait have been

3 demonstrated.[28]

4 Dynamic balance in walking was measured by the Dynamic Gait Index[29]. Dynamic Gait

5 Index assessed dynamic postural stability as functional gait according to eight tasks with

6 varying demands including walking at different speeds, walking with head movements,

7 negotiating obstacles, turning, ascending and descending stairs. Each item was rated on a 4-

8 level ordinal scale, with a maximum score of 24[29]. The Dynamic Gait Index has been

9 regularly used as a outcome measures in clinical trial for patients with balance problems [30,31].

10

11 Severity of dizziness (an average level over the previous few days) was measured with a

12 10 cm visual analogue scale. The visual analogue scale has been used to measure dizziness in

13 other clinical studies.[5]

14

15 Frequency of dizziness was measured on a six-point rating scale (0=no dizziness, 1=dizziness

16 less than once per month, 2=1–4 episodes of dizziness per month, 3=1–4 episodes of

17 dizziness per week, 4=dizziness once daily, 5=dizziness more than once a day or constant).[32]

18

19 Active cervical range of motion was measured with a strap-on head goniometer consisting of

20 an inclinometer dial for measuring flexion, extension and lateral flexion and a compass dial

21 for measuring rotation (OB ''Myrin'' goniometer, OB Rehab, Solna, Sweden).[33]

22

23 Statistical analysis

1   Statistical analysis was carried out with SPSS software (Version 19.0). Intraclass correlation

2   coefficient ($ICC_{3,k}$) with 95% confidence interval and standard error of measurement (SEM)

3   [34]was calculated to determine intra-rater reliability of the three repeat measures of time

4   average mean velocities of the upper and lower vertebral arterial blood flow in each session.

5   Paired t-test was used to determine the differences in the time average mean velocities of

6   blood flow at the same site of the vertebral artery and the clinical outcome measures in two

7   sessions three weeks apart. Level of significance was set at 0.05. Post hoc power calculation

8   was carried out to determine the type II error when no significant differences were found in

9   the outcome measures between the two sessions.

1 **Results**

2 Participant characteristics were presented in table 1.

3 The mean $ICC_{3,k}$ for measuring the blood flow velocities in the vertebral artery at upper and

4 lower cervical levels were found to be highly repeatable within each session (Table 2 and 3)

5 and between session (Table 4). All the ICC values were greater than 0.900. The ICC ranges

6 from 0.903 - 0.957 in the first session, 0.930 - 0.967 in the second session and 0.922 - 0.984

7 between the two sessions three weeks apart.

8 Paired t-tests revealed no significant statistical differences in both the time average mean

9 velocities and clinical outcome measures between the two assessment sessions three weeks

10 apart ($p > 0.05$, Table 5 and 6).

11 The clinical outcome measures suggested that patients with cervicogenic dizziness in this

12 study were being affected significantly in the balance and quality of life. There was a high

13 pain level, severity of dizziness and frequency of dizziness (Table 6). The mean score of

14 48.11 out of 100 of the Dizziness Handicap Inventory suggested that this group of patients

15 with cervicogenic dizziness have moderate handicap[25] (Table 6).

16

17

18

19

20

21

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 three week period. The reliability of the described method was found to be 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]

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 has also 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 average mean velocities when the patients were measured three weeks apart ($p > 0.05$, Table 5 and 6). A compromise post-hoc power analysis was carried out to identify the statistical power [36] [37] 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).

1   This study demonstrated an excellent between-session repeatability (ICC: 0.922 -

2   0.984) in measuring the vertebral arterial blood flow velocities in patients with cervicogenic

3   dizziness. The vertebral arterial blood flow is readily identifiable at the upper and lower

4   cervical spine; the use of body landmarks and the real time visualisation of the entry of the

5   vertebral artery to transverse foramen from the Doppler imaging as well as standardisation of

6   protocol described in the methodology ensured good repeatability.

7

8   **Limitations**

9   There were some individual variations in the blood flow velocities with quite a large

10   standard deviation (Table 5). This may limit the use of Doppler ultrasound as a diagnostic

11   tool in assessing patients with cervicogenic dizziness. However, we have demonstrated that

12   determination of time average mean velocities from the Doppler ultrasound at the upper and

13   lower vertebral arteries could be used for evaluation for within-subject pairwise comparison

14   in clinical population. In this study, one of the limitations is that the order of measuring was

15   not randomized which was to ensure the standardization of the procedures.

16

17   **Conclusion**

18   This study provides a foundation for the use of Doppler ultrasound in the assessment

19   of patients with cervicogenic dizziness. The repeatability of time average mean velocities was

20   excellent between measurements taken three weeks apart when there was no change in

21   clinical outcome measures. Therefore, measuring vertebral arterial blood flow velocities at

22   C0-1 and C5-6 could provide a clinically meaningful outcome measure to identify potential

1   changes in mean blood flow velocity before and after intervention in people with

2   cervicogenic dizziness in future studies. If the clinical outcome of patients improved after an

3   intervention, it would be valuable to see if changes occur in the time averaged blood flow

4   velocities as this would demonstrate the role of vertebral artery blood flow in patients with

5   cervicogenic dizziness.

6

7   This is the first study to measure the blood flow velocities in patients with

8   cervicogenic dizziness over a three week period. The Doppler ultrasound findings

9   demonstrated a very good reliability and it corroborated with the clinical outcome

10   measurements. Further research is planned to provide an intervention to improve the

11   symptoms in people with cervicogenic dizziness and investigate if blood flow changes will

12   occur when the clinical symptoms improve. This will improve our understanding of the role

13   of vertebral artery involvement in cervicogenic dizziness.

14

1 **References**

2 1. Colledge NR, Barr-Hamilton RM, Lewis SJ, Sellar RJ, Wilson JA. Evaluation of

3   investigations to diagnose the cause of dizziness in elderly people: a community based

4   controlled study. BMJ. 1996;313:788-92.

5 2. Furman JM, Whitney SL. Central causes of dizziness. Phys Ther. 2000;80:179-87.

6 3. Yardley L, Redfern MS. Psychological factors influencing recovery from balance

7   disorders. J Anxiety Disord. 2001;15:107-19.

8 4. Brandt T, Bronstein AM. Cervical vertigo. J Neurol Neurosurg Psychiatry. 2001;71:8-12.

9 5. Heikkila H, Johansson M, Wenngren BI. Effects of acupuncture, cervical manipulation

10   and NSAID therapy on dizziness and impaired head repositioning of suspected cervical

11   origin: a pilot study. Man Ther. 2000;5:151-7.

12 6. Reid SA, Rivett DA. Manual therapy treatment of cervicogenic dizziness: a systematic

13   review. Man Ther. 2005;10:4-13.

14 7. Wrisley DM, Sparto PJ, Whitney SL, Furman JM. Cervicogenic dizziness: a review of

15   diagnosis and treatment. J Orthop Sports Phys Ther. 2000;30:755-66.

16 8. Biesinger E. Vertigo caused by disorders of the cervical vertebral column. Diagnosis and

17   treatment. Adv Otorhinolaryngol. 1988;39:44-51.

18 9. Fitz-Ritson D. Assessment of cervicogenic vertigo. J Manipulative Physiol Ther.

19   1991;14:193-8.

20 10. Newell DW, Aaslid R. Transcranial Doppler. Lippincott Williams and Wilkins: New

21   York. 1991.

22 11. Creighton D, Kondratek M, Krauss J, Huijbregts P, Qu H. Ultrasound analysis of the

23   vertebral artery during non-thrust cervical translatoric spinal manipulation. J Man Manip

24   Ther. 2011;19:84-90.

1   12. Mitchell J, Keene D, Dyson C, Harvey L, Pruvey C, Phillips R. Is cervical spine rotation,

2   as used in the standard vertebrobasilar insufficiency test, associated with a measureable

3   change in intracranial vertebral artery blood flow? Man Ther. 2004;9:220-7.

4   13. Mitchell J. Doppler insonation of vertebral artery blood flow changes associated with

5   cervical spine rotation: Implications for manual therapists. Physiother Theory Pract.

6   2007;23:303-13.

7   14. Mitchell J. Vertebral Artery Blood flow Velocity Changes Associated with Cervical

8   Spine rotation: A Meta-Analysis of the Evidence with implications for Professional

9   Practice. J Man Manip Ther. 2009;17:46-57.

10   15. Haynes MJ. Vertebral arteries and neck rotation: Doppler velocimeter and duplex results

11   compared. Ultrasound Med Biol. 2000;26:57-62.

12   16. Schöning M, Scheel P. Color duplex measurement of cerebral blood flow volume: intra-

13   and interobserver reproducibility and habituation to serial measurements in normal

14   subjects. J Cereb Blood Flow Metab. 1996;16:523-31.

15   17. Johnson C, Grant R, Dansie B, Taylor J, Spyropolous P. Measurement of blood flow in

16   the vertebral artery using colour duplex Doppler ultrasound: establishment of the

17   reliability of selected parameters. Man Ther. 2000;5:21-9.

18   18. Lui EY, Steinman AH, Cobbold RS, Johnston KW. Human factors as a source of error in

19   peak Doppler velocity measurement. J Vasc Surg. 2005;42:972-9.

20   19. Bozgeyik Z, Berilgen S, Ozdemir H, Tekatas A, Ogur E. Evaluation of the effects of

21   sildenafil citrate (viagra) on vertebral artery blood flow in patients with vertebro-basilar

22   insufficiency. Korean J Radiol. 2008;9:477-80.

1 20. Mitchell J, Kramschuster K. Real-time ultrasound measurements of changes in

2   suboccipital vertebral artery diameter and blood flow velocity associated with cervical

3   spine rotation. Physiother Res Int. 2008;13:241-54.

4 21. Refshauge KM. Rotation: a valid premanipulative dizziness test? Does it predict safe

5   manipulation? J Manipulative Physiol Ther. 1994;17:15-9.

6 22. Thiel H, Wallace K, Donat J, Yong-Hing K. Effect of various head and neck positions on

7   vertebral artery blood flow. Clin Biomech. 1994;9:105-10.

8 23. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power

9   3.1: tests for correlation and regression analyses. Behav Res Methods. 2009;41:1149-60.

10 24. Clendaniel RA. Outcome measures for assessment of treatment of the dizzy and balance

11   disorder patient. Otolaryngol Clin North Am. 2000;33:519-33.

12 25. Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory.

13   Arch Otolaryngol Head Neck Surg. 1990;116:424-7.

14 26. Newman C, Jacobson G. Application of Self-Report Scales in Balance Function

15   Handicap Assessment and Management. Semin Hear. 1993;14:363-75.

16 27. Enloe LJ, Shields RK. Evaluation of health-related quality of life in individuals with

17   vestibular disease using disease-specific and general outcome measures. Phys Ther.

18   1997;77:890-903.

19 28. Whitney SL, Wrisley DM, Brown KE, Furman JM. Is perception of handicap related to

20   functional performance in persons with vestibular dysfunction? Otol Neurotol.

21   2004;25:139-43.

22 29. Wrisley DM, Walker ML, Echternach JL, Strasnick B. Reliability of the dynamic gait

23   index in people with vestibular disorders. Arch Phys Med Rehabil. 2003;84:1528-33.

1 30. Karapolat H, Celebisoy N, Kirazli Y, Ozgen G, Gode S, Gokcay F et al. Is vestibular

2   rehabilitation as effective in bilateral vestibular dysfunction as in unilateral vestibular

3   dysfunction? Eur J Phys Rehabil Med. 2014;50:657-63.

4 31. Smaerup M, Gronvall E, Larsen SB, Laessoe U, Henriksen JJ, Damsgaard EM.

5   Computer-assisted training as a complement in rehabilitation of patients with chronic

6   vestibular dizziness--a randomized controlled trial. Arch Phys Med Rehabil.

7   2015;96:395-401.

8 32. Karlberg M, Magnusson M, Eva-Maj M, Agneta M, Moritz U. Postural and symptomatic

9   improvement after physiotherapy in patients with dizziness of suspected cervical origin.

10   Arch Phys Med Rehabil. 1996;77:874-82.

11 33. Whittingham W, Nilsson N. Active range of motion in the cervical spine increases after

12   spinal manipulation (toggle recoil). J Manipulative Physiol Ther. 2001;24:552-5

13 34. Portney LG, Watkins MP. Foundations of clinical research : applications to practice.

14   Pearson: New Jersey. 2009.

15 35. Kottner J, Audige L, Brorson S, Donner A, Gajewski BJ, Hróbjartsson A et al.

16   Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were proposed.

17   Int J Nurs Stud. 2011;48:661-71.

18 36. Mayr S, Erdfelder E, Buchner A, Faul F. A short tutorial of GPower. Tutor Quant

19   Methods Psychol. 2007;3:51-9.

20 37. Faul F, Erdfelder E, Buchner A, Lang A-G. Statistical power analyses using G*Power

21   3.1: tests for correlation and regression analyses. Behav Res Methods. 2009;41:1149-60

22

1 **Figure legends**

2

3 Figure 1. Doppler ultrasound imaging measured at the lower cervical spine between fifth

4 cervical vertebra and sixth cervical vertebra.
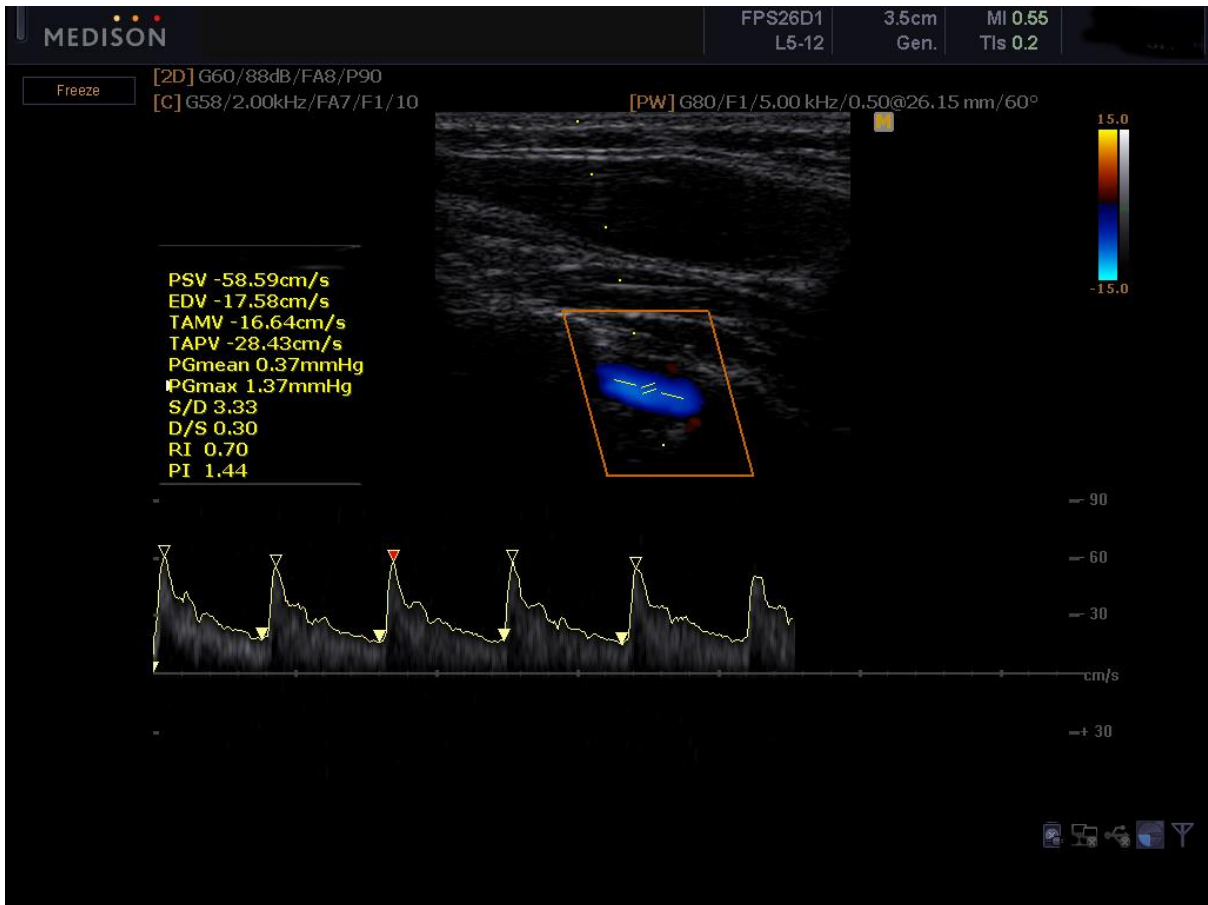
5

6

1   Figure 2. Doppler ultrasound imaging measured at the upper cervical spine at atlanto-

2   occipital joint as the vertebral artery exited from the transverse foramen of atlas and passed

3   onto the posterior arch of the atlas.

4

1   Table 1. Baseline characteristics of participants

2

Age (years)	45.1 ± 9.2
Weight (kg)	72.64 ± 10.80
Height (m)	1.68 ± 0.07
Onset of symptoms (months)	94.0 ± 65.9
Gender	Male: 5; Female: 7

3

4

5

6

7

1   Table 2. Within-session Intraclass correlation (ICC) at the first session

2

	ICC of the time averaged mean velocities (TAMV)	95% Confidence Interval (CI)	Standard Error of Measurement (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

3

4

5

6

7

1   Table 3. Within-session Intraclass correlation (ICC) at the second session (three weeks later)

2

	ICC of the time averaged mean velocities (TAMV)	95% Confidence Interval (CI)	Standard Error of Measurement (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

3

4

5

1 Table 4. Intraclass correlation (ICC) between the two sessions (first session vs second

2 session)

3

	ICC of the time averaged mean velocities (TAMV)	95% Confidence Interval (CI)	Standard Error of Measurement (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

4

5
6

7

1   Table 5. Time averaged mean velocities(TAMV) of the two sessions
2

	TAMV (cm/s) (mean ± SD)		P	Power (%)
	First session	Second session (3 weeks later)		
Right vertebral artery at C5/6	14.07 ± 3.57	14.28 ± 3.69	0.431	88.59
Left vertebral artery at C5/6	12.51 ± 4.78	12.06 ± 4.57	0.316	99.99
Right vertebral artery at C0/1	11.17 ± 3.58	10.93 ± 3.47	0.500	94.83
Left vertebral artery at C0/1	13.73 ± 4.29	13.63 ± 4.69	0.943	97.82

3

4   Paired t test revealed no significant differences in the time averaged mean velocities (cm/s)

5   between two sessions three weeks apart.

6

1   Table 6. Clinical outcome measures between the two sessions

2

	First session	Second session (3 weeks later)	P
Dizziness Handicap Inventory(Max: 100)	48.11 ± 16.19	48.15 ± 15.33	0.957
Dynamic gait index (Max: 24)	21.69 ± 1.55	22.15 ± 1.46	0.351
Visual analogue scale of neck pain (Max: 10)	7.31 ± 1.7	6.69 ± 1.65	0.359
Visual analogue scale of severity of dizziness (Max: 10)	5.69 ± 1.75	5.84 ± 1.68	0.165
Frequency of dizziness (Max: 5)	3.85 ± 1.21	3.77 ± 1.42	0.584
Neck rage of motion (degrees)			
Flexion	38.08 ± 10.9	41.92 ± 9.9	0.192
Extension	41.15 ± 9.61	42.69 ± 8.81	0.165
Rotation at the more restricted side	53.85 ± 11.21	51.54 ± 9.21	0.165
Rotation at the less restricted side	60.00 ± 10.41	56.92 ± 9.69	0.431
Side flexion at the more restricted side	28.08 ± 6.63	30.00 ± 7.91	0.175
Side flexion at the less restricted side	31.92 ± 6.30	30.38 ± 8.53	0.264

3

4   Paired t test revealed no significant differences in the clinical outcome measures ($p > 0.05$).

5