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● *Original Contribution*

VERTEBRAL ARTERIES AND NECK ROTATION: DOPPLER VELOCIMETER AND DUPLEX RESULTS COMPARED

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Abstract—The purpose of this study was to test the validity of Doppler ultrasound (US) velocimeter examination of vertebral arteries during contralateral (to the opposite side) cervical rotation. Vertebral arteries from 20 subjects were insonated using a bidirectional Doppler velocimeter at the suboccipital portal (standard technique) and C2 transverse process level (new technique) during contralateral cervical rotation. The results, regarding persistence or major reduction in Doppler signals, were then compared with those from a colour-flow duplex US scanner using the same procedure. There was complete agreement between the combined suboccipital and C2 velocimeter results and those from the duplex scanner (k = 1.00 at p = 0.01): both sensitivity (n = 5) and specificity (n = 34) were 100%. This study provides evidence to support the validity of bidirectional Doppler velocimeter examination, by an experienced examiner, for the purpose of assessing the effects of contralateral rotation on vertebral artery blood flow.

Key Words: **Vertebral artery, Flowmeters, Ultrasonic diagnosis, Cervical vertebrae, Chiropractic.**

INTRODUCTION

Studies using technologies that incorporate imaging, such as arteriography (Faris et al. 1963), magnetic resonance angiography (Weintraub and Khoury 1995) and duplex ultrasound (US) scanning (Cote et al. 1996) have demonstrated that blood flow through vertebral arteries can be restricted as a result of neck rotation, especially on the contralateral or opposite side to rotation.

Two studies, one using a Doppler velocimeter (Arnetoli et al. 1989) and the other employing magnetic resonance angiography (Weintraub and Khoury 1995), found that this phenomenon constituted an independent risk factor for stroke. Cases of stroke (*e.g.*, lateral medullary syndrome) following cervical manipulation have been reported (Terrett 1987; Haynes 1994), and Arnetoli et al. (1989) recommended that Doppler velocimetery of vertebral arteries during neck rotation be used in premanipulative screening.

The cadaveric studies of Selecki (1969) indicated that the cause of restricted blood flow that can occur in vertebral arteries during neck rotation is initially due to compression, especially at the C2 level, and that, with further rotation, the artery can be stretched. Loss of Doppler signals from a vertebral artery due to head rotation may be clinically important, if it indicates that the artery has been compressed and, perhaps, stretched (Haynes 1996). In these cases, neck manipulation could result in more rotation that might traction the artery sufficiently to cause intimal disruption, thrombus formation and, possibly, stroke. Conversely, persistence of the Doppler signals may suggest that the artery has not been elongated by the movement of the neck, and that it would be very unlikely for the vessel to be overstretched by cervical manipulation.

Most studies that have compared simple Doppler examination with arteriography (used as the "gold standard") in assessing the patency of vertebral arteries with the head in the neutral position have shown close agreement; values of sensitivity ranging from 85% to 87%, and specificity from 94% to 100% (Kaneda et al. 1977; Hennerici et al. 1981; Ringelstein et al. 1985). However, there seem to be no studies on the validity of Doppler velocimeter examination of vertebral arteries during cervical rotation. The aim of this pilot study is to test the hypothesis that Doppler velocimeter examination is valid in determining the effects of contralateral cervical rotation on the blood flow of vertebral arteries, by comparing velocimeter results with those obtained from a duplex scanner.

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The terms "valid" and "validity" in this study have been used purely in the strict sense of concordance levels between the results of subjective assessment of Doppler velocimeter examination and quantitative measurements using duplex. Qualitative assessment of velocimeter audio signals, rather than analysis of chart recordings, was used because this study was a test of how well the most basic and least expensive setup for bidirectional Doppler performed against the duplex scanner.

MATERIALS AND METHODS

Subjects

There were 11 women and 9 men as subjects; their ages ranged from 20–52 y, the average being 39 y (SD = 4.2). The sample was recruited from patients who had initially presented with neck-related symptoms at the chiropractic clinic of the author, but were symptom-free at the time of the trials. (The difficulty in obtaining access to a duplex scanner prevented a larger sample size being generated.) None of the subjects suffered from dizziness or other symptoms suggestive of vertebro-basilar insufficiency, nor severe restriction in neck rotation at the time of examination. Other than this, no exclusion criteria were applied to the subjects. Ethics approval for this study was granted by The University of Western Australia Committee for Human Rights. All subjects provided their informed consent to participate.

Equipment

A 5-MHz Hadeco Bi-dop ES-100VII (Hayaski Denki Co Ltd, Kawasaki, Japan) continuous wave bidirectional (hand-held) Doppler velocimeter was employed because of its ability to determine the direction of blood flow. The results of the Doppler studies were compared with those obtained from an ATL Ultramark 9 colour duplex scanner (Bothel, WA).

A mercury sphygmomanometer was used to measure blood pressures, and the degrees of head rotation were measured using a cervical ranges of motion (CROM) device, according to the instructions in the manual that came with it (Performance Attainment Associates 1988). To measure neck rotation, a CROM employs a compass needle mounted on a perspex frame that is worn like a pair of spectacles by the subject, who sits during the examination. Studies have demonstrated that the CROM device has acceptable interexaminer reliability (Capuano-Pucci et al. 1991; Rheault et al. 1992). There was no evidence of any interaction between the CROM and the scanner.

PROCEDURE

Doppler velocimeter studies

Blood pressures were measured from both arms of the subjects who were seated, and then Doppler velocimeter examinations were performed, also with the subjects sitting. Arteries were insonated using the Hadeco bidirectional unit on audio only with a 5-MHz probe, first at the suboccipital portal using a procedure previously described (Hennerici et al. 1981; Haynes 1995). The probe was placed against the suboccipital region slightly posterior to the mastoid process and positioned to obtain the clearest vertebral artery signals possible while the head was in the neutral position (Fig. 1).

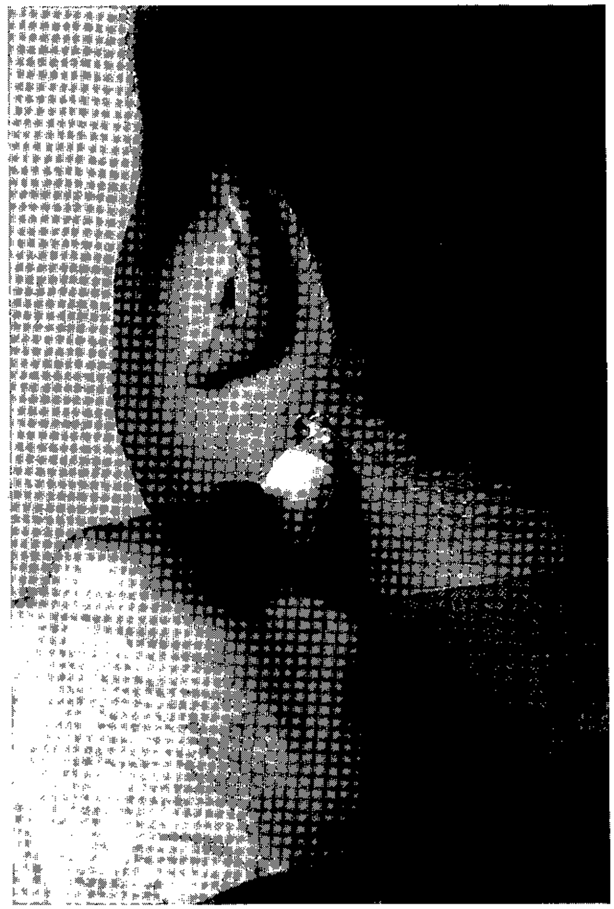

Fig. 1. Placement of the Doppler velocimeter probe for vertebral artery insonation at the suboccipital portal.

A new portal of examination, namely at the level of the axis transverse process (Haynes 1995), was used in addition to insonate the vertebral arteries with the velocimeter. The probe is directed medially and, occasionally with a slight antero-superior inclination, to gain clearer signals (Fig. 2). At the C2 transverse process, the US beam can strike the vertebral artery blood flow end-on (Haynes 1995), which is an ideal situation for producing strong Doppler signals (Zagzebski 1992).

The subjects were asked to slowly turn their heads contralaterally (away from the side the probe was positioned) to the end range (*i.e.*, as far as they could do so

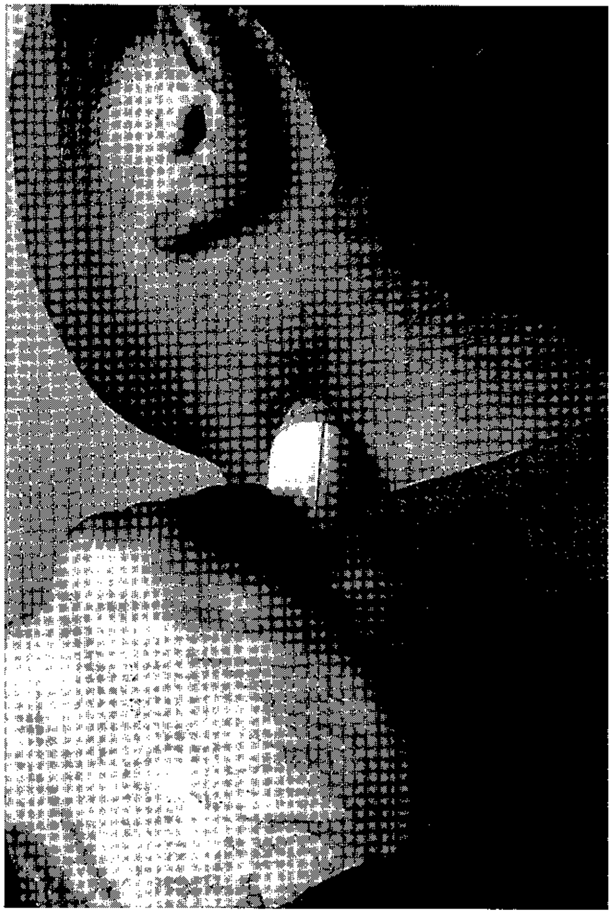

Fig. 2. Placement of the Doppler velocimeter probe for vertebral artery insonation at the C2 transverse process portal.

comfortably), and the probe was moved slightly as required to maintain optimum signals. The degrees of rotation at which major changes in velocimeter signals occurred were measured by the CROM instrument, and recorded. The effects on the Doppler signals were recorded as: no change, markedly reduced signals, and major increases in signals. Signals were classified as being markedly reduced if normal signals in the neutral position developed a high resistance character (*i.e.*, a loss of the low-pitched diastolic sound) and a lower amplitude or were lost completely during neck rotation, and also if weak signals in the neutral position were totally extinguished with rotation. Major increases in signals were defined by conspicuously higher amplitude and pitch.

For each vertebral artery, at both suboccipital and C2 portals, Doppler examinations were made three times. Hence, there was a total of 240 Doppler examinations attempted (*i.e.*, 3 examinations × 2 examination sites; suboccipital and C2, × 2 sides; left and right, × 20 subjects), or expressed differently = 80 sets of 3 examinations. Velocimeter determination of blood-flow persistence (*i.e.*, normality) during rotation was made if velocities were observed to be relatively unchanged with at least one examination at either the suboccipital or C2 levels. Results were considered to be positive for major decreases in signals if this was observed in all examinations of the artery at both portals.

Duplex scanning studies

The duplex scanning studies were made no more than 3 weeks after the Doppler velocimeter examinations, during which time all subjects remained apparently healthy. Blood pressures were measured prior to the duplex scanner examination and cervical rotation was measured during the study. Three sonographers with extensive experience in vertebral artery scanning were kept unaware of the results of the velocimeter studies, and made scans according to a set protocol. Duplex scanning was performed at the private clinic of a vascular surgeon, on the subjects who sat upright, and followed a standard procedure described in the literature for scanning the midsection of the artery (Bartels et al. 1992). The artery was first scanned at the C3/4 level and Doppler velocity measurements were taken from the midportion of the lumen. The scanner was operated on 7.5 MHz for the imaging facility with the wall filter set low, and a Doppler frequency of 5MHz was selected.

The C1/C2 segment of the artery was located by tracking the vessel from C3/C4 up to the C1/C2 level, where the probe was placed below the mastoid process and directed superior-medially. Colour-flow Doppler imaging was used to facilitate location of the vertebral artery at this level. At C1/C2, velocity measurements were taken at the minimum angle to the flow as the vessel deviated toward the probe, because the Doppler response is most pronounced when the beam strikes the column of moving blood cells end-on (Zagzebski 1992).

Scanner measurements of peak systolic and diastolic velocities at C3/4 were made in the neutral position and sequentially at each 10° of rotation to the same end range as determined in the earlier velocimeter study. At C1/C2, these measurements were taken twice both in the neutral position and at the end range.

Data analysis

"Blinded" comparison was made of velocimeter and duplex scanner data. Values of sensitivity and specificity were calculated and confidence intervals set at 0.05. Concordance between the velocimeter and duplex results was calculated using the Cohen's kappa for nominal scores statistic (Fleiss 1991) and the level of significance set at 0.01. To compare concordance results the significance for two independent kappas (Haas, 1991) was determined. A kappa score of 0.75 or more indicates

Table 1. Mean active cervical spine rotation of 20 subjects for both sides

	Cervical rotation in degrees	
Subjects	Left	Right
Male $n = 9$	67.5 SD = 12.9	69.0 SD = 8.7
Female $n = 11$	68.0 SD = 13.2	69.0 SD = 11.9
Total $n = 20$	67.7 SD = 12.6	69.0 SD = 10.6

excellent agreement, while scores between 0.40 to 0.75 indicate fair to good agreement. Poor levels of concordance are signified with scores less than 0.40 (Fleiss, 1981).

RESULTS

Cervical rotation and blood pressures

In all but 2 subjects, active cervical rotation occurred within the ranges observed by Youdas et al. (1992), who used a CROM instrument to determine normal values of active cervical ranges of motion in healthy males and females of different age groups. The data from the present study are shown in Table 1. The 2 subjects had rotation slightly less than the minimum range. However, data from their examinations were included in the study because the ranges of their rotation were constant for both the Doppler and duplex studies and, therefore, would not have confounded the results. Blood pressures of the subjects were within normal limits except for 1 subject, a 20-year-old woman who was hypertensive (146/88) and pregnant. The average blood pressure for the women was 113/69 and for the men it was 123/81, and no subjects displayed any major individual differences in their blood pressures taken for the Doppler study and the duplex study.

Doppler velocimeter

All the vertebral arteries from the 20 subjects were able to be insonated by the velocimeter at the suboccipital portal. Of the arteries at the C2 portal, 32 (80%) had clearly displayed flow toward the probe of the bidirectional velocimeter; so from a possible 80 sets of examinations from the 40 vertebral arteries examined, 72 were successfully made. A total of 5 arteries from 4 subjects displayed a marked decrease in audible Doppler signals during contralateral rotation, and 4 of these arteries had displayed complete loss of signals. Both the vertebral arteries from 1 subject displayed markedly increased (higher pitch and amplitude) Doppler signals at the C2 level with full contralateral cervical rotation, but had not shown any changes at the suboccipital level.

Duplex scanning

Duplex scanning of vertebral arteries was possible with 39 of the possible 40 arteries. Of 39 vertebral arteries able to be duplex scanned, 5 arteries from 3 women ages 26, 41 and 52 y and 1 man age 56 y showed marked decreases, ranging from 35% to 68% in peak systolic blood velocities, with attendant spectral broadening of the velocity profiles during contralateral rotation (Table 2). In 2 of these arteries, a marked increase in velocities followed the decrease (*i.e.*, a possible hyperaemic response to mild ischaemia) as the head was turned toward the neutral position. In all 5 cases, the reduction in velocities occurred close to the end range of rotation. Two arteries from one subject at the C1/2 level had blood velocities markedly increased with spectral broadening of the wave form at the limit of rotation (Table 2), and localised compression of the arteries as they left the C2 foramen was observed. No subjects suffered from any symptoms of vertebro-basilar insufficiency at any time during the study.

Concordance

The Doppler and duplex results from 39 of the 40 vertebral arteries were compared because 1 artery could not be duplex scanned. Agreement between Doppler

Table 2. Peak systolic blood velocities of affected vertebral arteries (VA) measured by duplex scanning with the head in the neutral position and at the end range of contralateral (to the opposite side) neck rotation

	Subject			Peak systolic velocity (cm/s)	
	Gender	Age	Artery	Neutral	Full rotation
Arteries displaying a marked decrease in blood velocities					
1.	F	51	RVA	37.4	10.1
2.	F	26	RVA	70.0	22.3
			LVA	69.4	21.6
3.	M	52	RVA	43.2	20.2
4.	F	41	LVA	35.1	22.9
Arteries displaying a marked increase in blood velocities					
5.	F	28	RVA	64.2	110.2
			LVA	66.3	150.3

M = male; F = female; RVA = right vertebral artery; LVA = left vertebral artery.

Table 3. Combined results of Doppler velocimeter examinations of vertebral arteries at the C2 and suboccipital levels compared to those from duplex scanning at the C3/4 level, during contralateral neck rotation

Velocimeter (C2 and suboccipital)	Duplex: Markedly reduced signals	Duplex: Unaffected signals
Markedly reduced signals	5	0
Unaffected signals	0	34

$k = 1.00$ at a 0.01 level of significance.
The new combined Doppler technique detected all the same 5 positive cases as did the duplex scanning, and revealed the same 34 negative cases as did the scanning studies. There were no false-positive nor false-negative results for combined Doppler examination results at both the suboccipital and C2 portals.

Table 4. Results of Doppler velocimeter examinations of vertebral arteries at the suboccipital level compared to those from duplex scanning at the C3/4 level, during contralateral neck rotation

Velocimeter (Suboccipital)	Duplex: Markedly reduced signals	Duplex: Unaffected signals
Markedly reduced signals	5	4
Unaffected signals	0	30

$k = 0.65$ at a 0.01 level of significance.
The standard Doppler technique at just the suboccipital level detected all the same 5 positive cases as did the duplex scanning, but did not reveal all of the 34 negative cases that the duplex scanning detected. The standard Doppler technique produced no false-negative results but had produced 4 false-positive results.

velocimeter and duplex scanning regarding marked reduction (*i.e.*, sensitivity) in vertebral artery flow velocities during the same amount of contralateral rotation was 100% ($n = 5$). The degree of agreement concerning the persistence of relatively unchanged signals (*i.e.*, specificity) was 84% (0.95 confidence interval $65\% < p < 95\%$) for the suboccipital velocimeter examinations ($n = 34$), and 100% (0.95 confidence interval $p > 90\%$) for the pooling of suboccipital and C2 examination results ($n = 34$). The velocimeter and scanning studies detected the same two vertebral arteries from 1 subject who had shown dramatic increases of blood velocities at the C2 level with full rotation, but had not found any other changes at the suboccipital level (velocimeter) or the C3/4 level (scanner).

Table 3 shows that, when comparing velocimeter and scanner results with regard to marked reduction or persistence of signals during rotation, there was excellent concordance ($k = 1.00$ at $p = 0.01$) for velocimeter results at the C2 and suboccipital levels combined. Table 4 shows good agreement ($k = 0.65$ at $p = 0.01$) for Doppler results at the suboccipital portal alone. The kappa score for velocimeter results obtained at C2 alone (not tabled) was 0.90 at $p = 0.01$, which is very good. The kappa score for the combined suboccipital and C2 portal examinations was significantly higher (at a 0.01 level) than for the suboccipital alone examination. No other significant differences in kappa scores could be found.

DISCUSSION

The very high level of concordance of the velocimeter and duplex examination results, (especially from combined C2 and suboccipital portals) indicates that vertebral artery Doppler velocimeter examination during contralateral rotation, by someone experienced in the technique, is valid. (The author had approximately 3 years of experience of routinely using Doppler US.) Although there were only 5 positive cases, the overall sample size was large enough to provide the kappa scores with a high level of significance (*i.e.*, at 0.01). Because kappa is the correct statistic to use in studies of concordance (Haas 1991), the sample size was adequate to test the hypothesis that the Doppler technique has high validity (concordance with duplex results). The small number of positive cases meant that meaningful confidence intervals could not be set for sensitivity levels. However, this does not greatly affect the evidence supporting the hypothesis being tested (*i.e.*, validity of the Doppler technique), because sensitivity and specificity levels (which are percentage agreement scores used in studies of screening tests) are not really appropriate concordance statistics. The reason for this is that percentage agreement does not indicate whether or not levels of concordance have occurred as a result of chance alone (Haas 1991). Sensitivity and specificity were included in the study, even though they are not ideal concordance statistics, because the vertebral artery Doppler technique may eventually be utilised in screening tests, if it can satisfy the criteria for inclusion.

It is important to note that the very close agreement between Doppler velocimeter and duplex scanning results was observed even when less pronounced positive results were included. However, the results also suggest that better concordance is obtained when initial Doppler velocimeter signals in the neutral position are strong. Repeated velocimeter examinations for each vertebral artery showed that better specificity was possible when such repetition is made. This is most likely because repetition increases the chance of successfully tracking the vertebral artery during neck rotation, thereby reducing the risk of obtaining false-positive results.

The significantly higher kappa score for combined suboccipital and C2 data than the suboccipital alone scores indicates that the new Doppler technique (*i.e.*, including the examination at C2) has greater validity than the standard technique at the suboccipital portal. It seems that false-positive results from the suboccipital site can be challenged by also making the examination at the C2 level, and *vice versa.*

There were 4 arteries that did have complete loss of Doppler velocimeter signals and yet had some flow, although markedly reduced, detected with the duplex scanner. The possible reason is that the scanner has a much higher power output (*i.e.*, up to 422 mW/cm^2) (Advanced Technology Laboratories) and is able to detect lower blood velocities than the Hadeco velocimeter (Hadeco), which has a power output of only 83 mW/cm^2. The marked increase in blood velocities of two vertebral arteries at the end range of neck rotation was probably due to a jetting effect caused by small localised compression at the C2 level.

CONCLUSION

The results of this study provide evidence to support the hypothesis that Doppler velocimeter examination (by someone experienced in the technique) of individuals having active cervical rotation within or close to normal limits, is valid in detecting major reductions in vertebral artery blood flow during contralateral (to the opposite side) cervical rotation. Factors that appear to be important in enhancing the validity of vertebral artery Doppler for this purpose include repeating the examination if Doppler signals are lost during neck rotation and if signals cannot be found, and trying to locate them with bidirectional Doppler at the C2 portal.

Replication studies with, preferably, larger sample sizes and perhaps including magnetic resonance angiography would help test the findings of the present study. The highly sophisticated imaging facility of MRA may be able to assist with *in vivo* studies on the main mechanism of reduced blood flow in vertebral arteries caused by neck rotation (*i.e.*, whether it is due primarily to localised compression of the arterial wall or stretching). Future reliability studies (interexaminer and intraexaminer), and further research into the clinical relevance of restricted blood flow in vertebral arteries during neck movement could also be helpful in determining the usefulness of the Doppler velocimeter technique.

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