CERVICAL ARTERY DISSECTION. A COMPARISON OF HIGHLY DYNAMIC MECHANISMS: MANIPULATION VERSUS MOTOR VEHICLE COLLISION

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ABSTRACT

Objective: To examine the similarities and dissimilarities between cervical chiropractic manipulative therapy and whiplash, and their respective relation to cervical artery dissection.

Data Sources: A literature synthesis used MEDLINE-PubMed and MANTIS literature searches. A total list of 99 relevant articles was generated. Additional references were collected from citations incorporated within the included articles.

Results: Both neck manipulation and motor vehicle collision events apply loads to the spinal column rapidly. While neck manipulation loads are slower to develop and displacements smaller, they may reach peak amplitudes on maximum effort comparable to those seen in low-velocity collision experiments. In contrast to reports that the vertebral artery experiences elongations exceeding its physiological range by up to 9.0 mm during simulated whiplash, strains incurred during cervical manipulative therapy have been reported to be approximately one ninth of those required for mechanical failure, comparable to forces encountered in the course of diagnostic range of motion examination. Additionally, long-lasting abnormalities of blood flow velocity within the vertebral artery have been reported in patients following common whiplash injuries, whereas no significant changes in vertebral artery peak flow velocity were observed following cervical chiropractic manipulative therapy.

Conclusions: Perceived causation of reported cases of cervical artery dissection is more frequently attributed to chiropractic manipulative therapy procedures than to motor vehicle collision related injuries, even though the comparative biomechanical evidence makes such causation unlikely. The direct evidence suggests that the healthy vertebral artery is not at risk from properly performed chiropractic manipulative procedures. (J Manipulative Physiol Ther 2005;28:57-63)

Key Indexing Terms: *Manipulation; Chiropractic; Cervical Artery Dissection; Whiplash Injuries*

Cervical artery dissection (CAD) involving the vertebral artery (VA) and internal carotid artery (ICA) is an uncommon condition that has been reported to occur in rare instances following both cervical chiropractic manipulative therapy (CMT)[1-5] as well as whiplash injury.[6-9] The precise etiology of CAD has not been established, with most authors considering its cause to be unknown and most likely multi-factorial.[10] However, trauma or trivial trauma to the neck is frequently cited in the literature as a risk factor. While there are superficial mechanical similarities between CMT and whiplash, both are rapid events that move the head with respect to the torso, there is significant disparity in the report of suspect incidents involving CAD between them. This work examines some of the similarities and dissimilarities in effort to offer explication of these differences.

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Pertinent Anatomy of the Cervical Arteries

The ICA arises from the common carotid artery at its bifurcation and is made up of 4 segments. The cervical segment rises vertically and is located posterior to the external carotid artery. The ICA lies below the sternocleidomastoid muscles and is separated from the external carotid artery by the styloglossus and stylopharyngeal muscles. It is situated anterior to the longus cervicis muscle, and anterior to the transverse processes of the upper third or fourth cervical vertebrae.[11] The ICA is known as the petrous

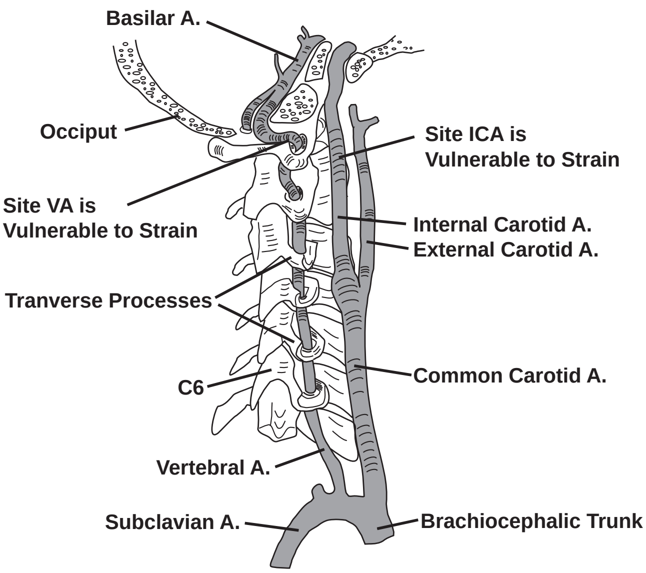

Fig 1. *Right anterolateral view of the relationships of VA and ICA to the cervical spine.*

segment after entering the carotid canal at the base of the skull. As the artery passes through the skull, it becomes the cavernous segment and ultimately the supraclinoid segment.[12] The ICA is freely moveable within its cervical pathway, but becomes fixed to the surface of the bone as it enters the carotid canal above the atlas.[13]

The VA typically arises from the subclavian artery and, like the ICA, has 4 segments. The prevertebral segment lies between the longus colli and the anterior scalene muscles prior to its entering the transverse foramen of C6. The cervical segment passes through the transverse foramina becoming the atlantal segment when it exits through the transverse foramen of C1. This segment transitions from traveling in a vertical direction to horizontal orientation, where it is thought to be most susceptible to injury related to sudden or extreme head movement.[14] The atlantal segment is sheathed in muscles, nerves, and passes through the atlanto-occipital membrane. The VA passes through a groove located behind the articular process of C1, before entering the cranium through the atlantooccipital membrane and the dura mater. The VA is fixed to adjacent structures in the tunnel formed by the transverse foramina by means of a continuous layer of collagen along its entire course (Fig 1).[15] As the intracranial segment, it continues upward across the medulla to the pontomedullary junction. There it joins with the opposite VA to become the basilar artery. The basilar artery extends distally to form the posterior inferior and anterior cerebellar arteries, the internal auditory artery, the superior cerebellar artery, the posterior cerebral artery, and numerous medullary and pontine branches. These arteries supply blood to the portions of the brain occupying the posterior fossa.[12]

Pathophysiology of CAD

Briefly, CAD may be caused by an initial tear of the artery's intimal lining, followed by blood penetrating into the muscular vessel wall. Pulsatile pressure undermines the muscular coat, resulting in a splitting or dissection of the layers. The separation may extend along the artery for variable distances, usually in the direction of blood flow.[16,17] Another mechanism is an intramural hemorrhage of the vasa vasorum that ruptures into the vessel's true lumen.[18,19] The disturbance in local blood flow associated with CAD promotes thrombus formation that may embolize blocking circulation more distally. Transient ischemia or infarction may result from the dissection. The mechanisms initiating intimal tears are uncertain. Some authors have indicated that tearing necessarily implies prior trauma.[20] However, tearing of the intima is common in cases of spontaneous CAD where no known trauma occurred. Hyperhomocysteinemia may represent a potential risk factor leading to structural abnormalities of the arterial wall and increasing the susceptibility to mechanical stress.[21]

When considering all extracranial CADs, ICA dissection (ICAD) occurs approximately 3 - 5 times more frequently than VA dissection (VAD).[19] VADs are much more likely to be claimed as associated with head movements, such as CMT or whiplash.[22] In a literature review of VAD in children, Hasan et al[23] noted an association between routine neck movements and the development of VAD in 50% of reported cases even though there was no exposure to sudden neck loading.

There is a distinction between classifications of spontaneous versus traumatic CADs depending upon whether or not there was a significant premorbid injury. The traumatic classification is reserved for cases associated with definite, and often severe, trauma. Major cervical spine trauma has been shown to be associated with VAD in about 24% of cases.[24] Mokri noted that there are conspicuous clinical differences between patients with spontaneous ICAD as compared with the traumatic variety.[25] He reported on a series of 95 patients, indicating that in traumatic dissections, aneurysms were more common, significantly fewer aneurysms resolved or became smaller, and fewer stenoses resolved or even improved. Post-traumatic stenoses progressed to occlusion more often and were more likely to leave the patients with neurological deficits. A significantly higher percentage of the patients with spontaneous dissections were asymptomatic at follow-up compared with the traumatic group. The prognosis from ICAD is controversial. Mokri[28] suggested a good rate of recovery without minimal residual deficit for the spontaneous type and a somewhat less favorable for the traumatic type. Milhaud et al,[26] on the other hand, have recently indicated that ICAD is a more severe disease than previously observed.

The VA is considered most susceptible to strain as it traverses the C1-C2 articulation[2] where it is thought most vulnerable to rotational movements.[11] The proposed mechanism during neck rotation is based on the ipsilateral C1 - C2

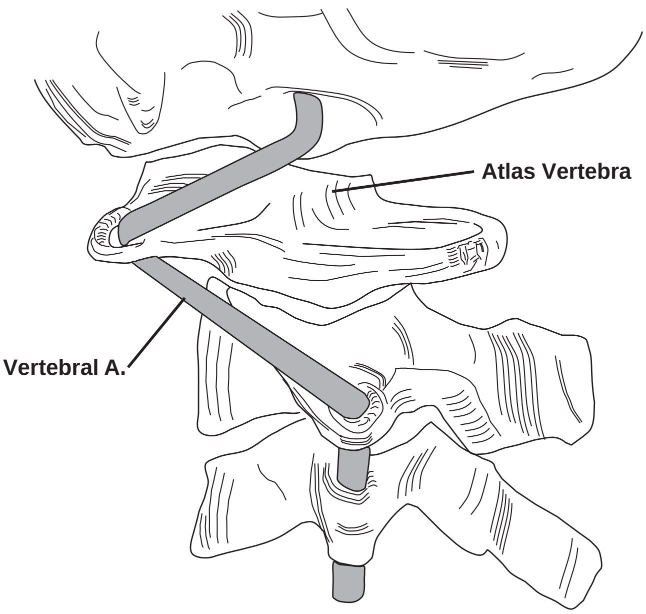

Fig 2. *The hypothetical mechanism of VA damage during rotation involves the contralateral side of C1 being propelled forward, which is supposed to stretch the left VA during right cervical rotation.*

joint being fixed, while the contralateral side of C1 is propelled forward, effectively stretching the VA (Fig 2). The ICA is most susceptible to strain with the head and neck in combined rotation or lateral flexion and coincident extension.[27] This positioning fixes the otherwise moveable ICA against the anterior surface of the upper cervical vertebrae, and thus becomes susceptible to injury.[28]

This work examines the understanding of mechanisms, available in the literature, for motor vehicle collision (MVC) and CMT loading of the cervical spine in effort to understand the disparity between reported claims of causation of arterial dissection between them.

Methods

Search Strategy

MEDLINE-PubMed and MANTIS were searched for the years 1966 through 2002. Only English language articles that purported to contain information pertaining to CAD causation, and all case studies and series were selected for review. A series of searches was performed, using the terms "cervical artery dissection," "vertebral artery dissection," and "internal carotid artery dissection," in combination with "cervical manipulation," "whiplash," and "sprain." A second search, using the term "stroke" in combination with "manipulation," "whiplash," and "sprain" was done. Finally, a search on "manipulation" and "biomechanics" related to the neck was done. Specific information on the biomechanical features of applied loads (forces and displacements) as well as vertebral artery mechanics and blood flow were sought. The literature generated by the searches was culled for citations incorporated within the articles.

The literature search strategy generated 99 papers. An additional 13 references were harvested from the reference lists of these articles.

Discussion

Forces and Displacements Encountered in Whiplash Compared with Cervical CMT

Van den Kroonenberg et al[29] carried out sled acceleration tests on human subjects to determine linear and angular head accelerations that were produced by velocity changes ranging from approximately 6.5 to 9.5 km/h. They observed that peak head linear accelerations were approximately 2.5 times greater than that of the sled. Head linear accelerations averaged 9 g, but ranged from 3-12 g. The value of the mean peak angular acceleration was 600 rad/sec^2. Similar tests were carried out by Croft et al,[30] who staged rear impact car-to-car crash tests with resulting velocity changes ranging from 2.9 to 10.1 km/h. The peak head linear acceleration values in these tests ranged from 2.5 to 13.3 g. There were no related injuries or subsequent symptoms reported by any of the participants in this study following the tests. Triano[31] found that CMT procedures also were rapid events with force development averaging 314 N/s and moments acquiring 371 Nm/s. Load rise time, however, was longer than most reported collision studies with peaks at 237 and 207 milliseconds, respectively.

Moments acting on the spine during simulated low-velocity collisions have been reported by a few investigators: Sances et al 1981, Ewing and Thomas (as reported by Sances 1981),[32] Patrick and Chou 1976,[33] and Gadd et al 1993.[34] A large range of loads were tolerated without adverse report from the volunteers with the exception of 1 subject who experienced a short interval of neck soreness at 88.1 Nm. Sagittal plane moments ranged from 50 to 94 Nm during rear impact while coronal plane loads from lateral impact studies were observed from 51 to 143 Nm.

Ono et al[35] found that the maximum head and neck extension angle during 4-8 km/h rear impact sled tests without head restraints was in the range of 40-56 degrees. This excursion was considered to be within normal limits. However, they pointed out that extension in the lower cervical spine was beyond normal physiological limits because of simultaneous axial compression forces that produced a phenomenon of initial upper cervical flexion, with lower cervical segmental hyperextension. The maximum axial compression value reported by the authors was 150 N, maximum lower cervical shear was 241 N, and subjects' heads reached maximum rearward excursion within 250 ms. One of 12 subjects involved in the study subsequently complained of minor neck discomfort that lasted 3 days.

Triano and Schultz[36] monitored triaxial linear and angular displacement time histories for the head during the

Table 1. *Load components observed during manipulation of the upper cervical spine during intended least effective to maximal clinical effort*

		Minimally Effective	Maximum Effort
Force	Transverse	54 N	93 N
	Axial	14 N	34 N
	Anteroposterior	22 N	43 N
Moment	Flexion/Extension	14 Nm	32 Nm
	Axial Rotation	32 Nm	50 Nm
	Lateral Bending	35 Nm	65 Nm

N = Newtons, Nm = Newton meters.

dynamic delivery of 2 CMT procedures; 1 intending to restrict and 1 to promote axial rotation. For the non-rotational maneuver, total displacements averaged 31° in flexion, 13° in rotation and 31° in lateral bending. Rotational maneuvers pre-positioned the head in rotation followed by a small increase during the dynamic thrust phase of the manipulation. Total mean displacements were observed at 50° in flexion, 25° in axial rotation and 33° in lateral bending. Hyperextension of the cervical spine has been implicated as an instigator of CAD[27] and cervical CMT is regularly applied to vertebral segments involving cervical extension. However, CMT does not create joint excursions beyond the physiological limits of the adjacent tissues.

External forces generated during cervical spine manipulation have been evaluated by Kawchuk et al.[37] They recorded mean peak forces of 117.7 N (+/− 15.6 N) with mean duration of the applied forces of 101.7 msec (+/− 14.7 msec). Triano[31] used an inverse dynamics model to estimate loads applied by the operator and those passing through the neck. Procedures were applied with the intention of ranging from least clinically effective to maximum clinical effort. When total external force estimates were compared with Kawchuk's direct measures of applied loads, the results were in excellent agreement. Transmitted loads that were observed are listed in Table 1. Like the experimental crash work, none of the volunteers for manipulation studies reported any significant adverse responses to participation in the study.

In the case of CMT, the manipulative thrust is applied by a skilled practitioner and is delivered with controlled amplitude and direction.[38] Collisions, on the other hand, involve loads acting in an unpredictable fashion that are dependent upon the number of impacts that are experienced, the directions applied and the relative mass and velocities of the colliding vehicles.

Vertebral Artery Mechanics and Blood Flow

Nibu et al[39] carried out experiments using post mortem human subjects in which they concluded that the vertebral artery was elongated to the point of significant traumatic strain during whiplash. They were able to quantify the extent of elongation using an *in vitro* model. Cervical spine specimens were dissected, while preserving the osteoligamentous structures. A nylon-coated flexible cable took the place of the right VA, which was secured to the occipital bone at one end and a custom VA transducer at the other end. The specimens were then mounted on a sled and exposed to horizontal accelerations of up to 8.5 g to simulate the whiplash event. This resulted in VA elongations that exceeded its physiological range by up to 9.0 mm when the head was rotated or laterally flexed.

Panjabi et al[40] more graphically described the mechanism reported by Nibu et al depicting the elongations and instantaneous configurations of the vertebral artery that were associated with whiplash. The authors pointed out that the cervical spine formed an S-shaped curve during the rearward phase of head excursion, with flexion occurring at the upper cervical levels and hyperextension at the lower levels. They indicated that the maximum stretch of the VA occurred during this phase of neck deformation from the whiplash event.

For cervical spine manipulation, however, Symons et al[41] found that the VA incurred strains that were approximately one ninth of those required for mechanical failure. By means of cadaveric studies, the authors set up an experiment where the VAs were instrumented with piezoelectric ultrasonographic crystals to record strains during range of motion and manipulative procedures. They also strained the VA until mechanical failure occurred, in order to determine the maximum tolerable strain value. The results of the study demonstrated that cervical manipulation resulted in average VA strain values of approximately 6.2% distally and 2.1% proximally. They indicated that these values were similar to, or lower than, what was recorded in the course of diagnostic range of motion examination. The VAs had to be stretched from 139% to 162% of their resting length before mechanical failure occurred during failure testing.

Blood flow velocity changes associated with whiplash events were studied by Seric et al.[42] They examined 47 patients who sustained injuries using transcranial Doppler sonography. Patients were evaluated within 1 month and then 6 months following injury. The authors determined that there were statistically significant disruptions of circulation that were manifested as either an increase or decrease in mean blood flow velocities. Within 1 month following injury, increased blood flow velocities affected 68% of left VAs, 62% of right VAs, and 51% of basilar arteries. They indicated that the velocity changes were most frequently associated with arterial spasm. There was also decreased blood flow within the first month that affected 25.5% of left VAs, 10.6% of right VAs, and 27.6% of basilar arteries. At 6 months follow-up, normal values were obtained in approximately 50% of the vessels, but abnormalities persisted in the remainder. They concluded that cervical spine lesions could affect VA blood flow and cause symptoms of vertebrobasilar insufficiency. Reddy et al[14] found similar abnormalities of blood flow velocity in trauma patients with relatively minor whiplash injuries, although their group was smaller.

Licht et al[43] carried out a randomized, controlled and observer-blinded study of VA blood flow changes from cervical manipulation. They measured VA peak flow velocity both before and after cervical manipulative therapy by means of Doppler ultrasound. In their group of 20 otherwise healthy subjects who had biomechanical dysfunction of the cervical spine, they found no significant differences in VA peak flow velocity following cervical manipulation. The authors had theorized that an increased peak flow velocity following cervical manipulation might explain the development of VA dissection that ensues on rare occasions. However, they concluded that in uncomplicated cervical manipulative therapy, this was not the case. In another study by Licht et al,[44] anesthetized adult pigs were dissected to expose the VA. Blood flow volume was then measured by means of advanced transit-time flowometry. A small and transient increase of VA volume flow following cervical CMT was detected, which only lasted 40 seconds.

The exact incidence rate of cervical CMT or whiplash related CAD is unknown,[45] and may be either higher[33] or lower than what the literature suggests as there are no good epidemiological data. Nearly all reports are case studies or case series that often claim causation based strictly on temporal relationship of the event to the appearance of symptoms. The difficulty with using temporal relationships as the sole basis for suspecting causation is that there are four interpretations available:

1) Event A causes event B.
2) Event B causes event A.
3) Both events A and B are caused by a third related event.
4) Neither A or B are related to each other or a third event but are coincidental.

While one cannot argue that a dissection event is responsible for the occurrence of a whiplash injury or a manipulation procedure being performed, the remaining 3 explanations are equally valid.

There are more than 200 reports in the literature of CAD occurring at some time following CMT. In contrast, there are few following MVCs. Moreover, CAD following MVC typically involves high-energy collisions, which result in more severe injuries than those seen in common whiplash.[14] Loads acting on the neck are similar only when CMT is compared with low energy collision where volunteer participants failed to show any adverse reactions in either the CMT or MVC test groups. Head displacements are generally smaller during CMT than those measured during MVC. Finally, arterial mechanics show significantly less elongation and strain in the CMT studies. VA blood flow, on the other hand, has a relatively high rate of altered flow velocities associated with whiplash injuries. Why then are there so many more reports of CAD in association with cervical CMT?

Absent significant evidence to explain the disparity between these reputed mechanisms of injury and the appearance of case claims in the literature, it is reasonable to look at the relative criteria used to claim causation of VAD. Selection bias has plagued most reports to date that present claims of causation by CMT. Selection of cases was based most often on the temporal relationship of the experience of manipulation by the patient at some time in the recent or remote past.

Alternative explanations and risk factors are frequently ignored.[46] Moreover, the claim incidence is artificially inflated in that each patient who has experienced an adverse event suspected of arising from CMT is seen by multiple neurologists who may separately report the event.[47] More obvious bias is evident in cases where the report has mislead the reader by attributing adverse reactions to "chiropractic" manipulation when manipulation was performed by orthopedic surgeons or therapists with no formal chiropractic training.[2,48]

Given that the initial symptoms of VAD commonly imitate the musculoskeletal pain for which patients typically consult chiropractors,[49,50] some of these patients may have already been in the process of experiencing CAD.[51] The associated CMT may have had little or nothing to do with the creation and progression of the ensuing dissection. This point is demonstrated by 5 cases presented by Terrett,[50] in which patients experienced CAD while waiting for treatment in the chiropractic physicians' office or after missing a scheduled chiropractic appointment. Had the planned CMTs actually been provided, the practitioners may have been accused for the subsequent CADs.

Numerous activities of daily living have been shown to negatively influence circulation of the cervical arteries in susceptible individuals and have been associated with CAD.[50] A few of these activities include: childbirth, positioning during surgery, yoga, overhead work, neck extension during x-ray procedures, neck extension for a nosebleed, turning the head while driving, archery, calisthenics, wrestling, emergency resuscitation, swimming, rap dancing, star gazing, sleeping position, beauty parlor events, and Tai Chi.

Most authors consider that an underlying arteriopathy, that has yet to be identified, must be present in CAD.[19,52] Some of the risk factors for CAD that have been mentioned are fibromuscular dysplasia, Marfan's Syndrome, cystic medial necrosis, ultrastructural connective tissue abnormalities, and infection in the weeks prior to CAD.[10,13,53] A recent target of this type of research is an abnormality in homocysteine metabolism that may weaken the arterial structure and predispose the artery to spontaneous damage. While significant effort has been made to identify lists of

Table 2. *Comparison of findings from cervical CMT and whiplash studies*

	Cervical CMT	Whiplash
Moments	14 to 65 Nm	51 to 143 Nm
Peak head linear acceleration	NA*	2.5 to 13.3 g
Force	14 to 93 N	150 to 241 N
Maximum head/neck angle	31-50 degrees in flexion	40-56 degrees in extension

* No data available.

Table 3. *Comparison of the effects on the vertebral artery of cervical CMT with whiplash injury*

	Cervical CMT	Whiplash Injury
Strain	VA Strain comparable to cervical range of motion examination.	VA Strain up to 9 mm beyond physiological limit.
Blood flow velocity	No significant changes in VA peak flow velocity following cervical manipulation.	VA blood flow abnormalities lasting six-months or more.

warning signs, there are none yet that seem able to identify patients who may be at risk for CAD.[41]

Conclusion

Reported cases of CAD from MVC are uncommon even from high-energy impact. Yet, perceived causation is more frequently attributed to CMT procedures even though the comparative biomechanical evidence makes such causation highly unlikely. Part of this disparity may be related to the higher number of cervical CMTs administered than MVCs. However, this does not account for the observations of significant arterial abnormalities associated with strain more often following MVC[40-43] Moreover, if strain to the cervical arteries were a primary causative factor in the development of CAD, one would expect to see the condition regularly following MVC and never following CMT.

Both neck manipulation and MVC events apply loads to the spinal column rapidly. While neck manipulation loads are slower to develop and displacements smaller, they reach peak amplitudes comparable to those seen in low-velocity collision experiments. A summary comparison of measurements resulting from the various studies is presented in Table 2 and a comparison of the disparate effects of whiplash and cervical CMT on the VA is presented in Table 3. The evidence suggests that the healthy vertebral artery is not at risk from properly performed CMT procedures. However, vulnerable arteries may be at risk associated with virtually any head movement, or the occurrence of spontaneous dissection. Furthermore, the development of CAD does not appear to be dependent upon the forces applied, rather on the artery's vulnerability. Unfortunately, there are no routine clinical procedures to differentiate between the two.

Neither of the experimental group participants from the various studies reviewed suffered any major adverse complaints. While it is desirable to identify risk factors and limit potential injury even when risk is small, such efforts should be carried out in an objective atmosphere, which is devoid as possible of bias and preconception, or worse, misuse of information.

The evidence provided here suggests that the healthy vertebral artery is not at risk from properly performed chiropractic manipulative procedures. For patients presenting with new neck and headache complaints, preceded by manipulation or motor vehicle collision or not, the best means to detect VA insufficiency is clinical vigilance. If circumstances are in doubt or suspicious, cases may warrant evaluation with Doppler ultrasound, magnetic resonance imaging or magnetic resonance angiography[54,55] before administering further care.

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