Topical update: The Hong Kong College of Pathologists, Incorporated in Hong Kong with Limited Liability

Volume 20, Issue 2, July 2025

Pathology of Vertebral Artery Trauma

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Editorial note:
Vertebral artery trauma involves potentially fatal injury that can lead to catastrophic outcomes including subarachnoid haemorrhage and cerebral ischemia. The pathology typically includes vessel rupture or dissection, which usually results from blunt trauma to the neck. Its severity often results in rapid collapse without prominent external findings. This Topical Update provides a proper approach to the diagnosis, etiology and mechanism of trauma. We welcome any feedback or suggestions. Please direct them to Dr. FOO Ka-chung (e-mail: kcfoo@dh.gov.hk) of Education Committee, the Hong Kong College of Pathologists. Opinions expressed are those of the authors or named individuals, and are not necessarily those of the Hong Kong College of Pathologists.

Introduction

Injury of the vertebral artery attaches special importance in forensic traumatology and denotes a mechanical insult to the neck or region around skull base, commonly inflicted during an assault. It is essential to understand its mechanism before offering appropriate opinion during court proceedings, especially on issues regarding the severity and nature of trauma.

Anatomy of Vertebral Artery

Human spine is a less commonly explored site during routine hospital autopsy. Proper examination requires a meticulous technique, patience and experience to ensure accurate documentation. There are intrinsic difficulties in delineating the pathology of spinal structures. The vertebral column is an obstacle for access and without proper instruments it is hard to breach the bony structure with precision. As the spine comprises multiple segments of vertebrae, intervertebral discs, ligaments, nerve branches, vascular channels, and spinal cord, preserving these structures would require detailed anatomical knowledge to navigate along. The spinal cord is prone to autolysis and hindered recognition of its proper architecture. Careful handling is essential.

The vertebral artery is a major paired vessels that supplies the posterior cerebral circulation, including the brainstem, cerebellum, and occipital lobes. They originate as branches of the first part of subclavian arteries, arising between the anterior scalene muscle and longus colli muscle. The artery is conventionally divided into four segments[i]. The *preforaminal segment*, denoted as V1, originates from its origin to the entry into transverse foramen of the sixth cervical vertebra (C6). It ascends along the neck, giving off small branches to surrounding muscles and structures. The *foraminal segment*, denoted as V2, ascends vertically through the transverse foramina from C6 to C2 vertebrae. This segment is well protected within the transverse processes. Examination therefore requires careful removal of the surrounding bony structures.

The *extradural segment*, denoted as V3, leaves the transverse foramen of C2, and curves postero-laterally around the lateral mass of the atlas (C1), then courses over the posterior arch of C1 before entering the foramen magnum through the dura mater. This segment is particularly tortuous and gives off small muscular branches for the cervical muscles and posterior cranial fossa by the meningeal branches. The *intradural segment*, denoted as V4, passes through the dura mater at the foramen magnum and becomes intracranial upon entering the posterior cranial fossa. It unites with the contralateral vertebral artery to form basilar artery, supplying the posterior cerebral circulation including branches of posterior inferior cerebellar artery (PICA) and anterior spinal artery[ii].

Autopsy Examination

Examining different segments of vertebral artery presents challenges to the pathologists due to its unique anatomical characteristics as mentioned above. An adequate examination necessitates removal of overlying muscles and bone structures. It demands precision to avoid damaging the vessel. As the vertebral artery ascends through the transverse foramina of the cervical vertebrae from C6 to C1 after emerging from the subclavian artery, a conventional approach[iii] would be an anterior Y-shaped neck incision[iv] plus a horizontal incision just above bilateral clavicle. The clavicle is then disarticulated at the sternoclavicular and acromioclavicular joints, obtaining a clear view of their origins. The rib cage should be sawed as laterally as possible to expose the thoracic cavity adequately. One should be cautious to avoid inadvertent severing of the vessels especially over the first few pair of ribs. The pharyngo-laryngeal structures can then be removed en-bloc with the pluck of thoracic organs, before exposing the pre-vertebral neck muscles, including the longus capitis, longus colli, and scalene muscles, etc. This is usually less time-consuming than operating on other segments. Routine instruments such as curved scissors, toothed forceps for grinding bony tissues, and plain forceps to grasp the artery could be employed for cutting transverse foramen. Boscolo-Berto et al suggested the use of a specially scissor like instrument "transversoclasiotome"[v], consisting of two cutting jaws and a knocker with a rounded tip in order to clearly expose the vertebral artery while minimizing the introduction of artefacts during dissection on adjacent tissues.

Alternatively, Galtes et al suggested a posterior approach to access the vetebroarterial canal[vi]. The spinal cord is first removed upon cervical bilateral laminectomy. The corresponding cervical cord is then transected and removed. An internal cut were made through the spinal canal at the antero-interior portion of the pedicle arranged in an outward and forward orientation. An external cut is made between the anterior and posterior tubercle of each of the transverse process and directed inward. This method, however, still requires meticulous clearance of muscles attached around the vertebrae and precise application of the cut into the transverse process.

Trauma and Dissection of Vertebral Artery

Both penetrating and blunt injuries can produce serious morbidity and mortality[vii]. Penetrating trauma[viii] by sharp cutting instruments or projectiles to the posterior triangle of neck may jeopardize the artery, leading to significant blood loss. Imaging modalities are advised to search for the site of contrast extravasation before correction by surgical or interventional radiology.

Blunt force trauma to the upper neck region can lead to serious and sometimes fatal consequences. These include tears or dissection of the vertebral artery, leading to haemorrhage within the surrounding tissues or into the cranial cavity. The latter condition can produce an almost instantaneous collapse. Milder cases can result in cerebral ischaemia and patients are often left with variable extent of neurological impairment. Certain injuries, such as dissection or complication by thrombosis, might not be immediately apparent but could evolve over hours or even days before producing appreciable clinical symptoms[ix]. These are primarily

related to vertebrobasilar insufficiency[xvii] with symptoms like headache, vertigo, dizziness, diplopia, dysarthria, nausea and gait disturbance[xv]. Delayed rupture of a traumatic laceration is rare but has been reported[x].

At times the interpretation of trauma or other pathology for an anatomically varied vessel could be confusing. Variants of the vertebral artery, though often asymptomatic, are also clinically important because they can impart a higher susceptibility to disease process, in particular the development of stroke, subclavian steal syndrome, and instrumentation-related injury during spinal operation. It may complicate interpretation of angiograms or other imaging modalities. Natural progression of disease process could also be modified or exacerbated when concomitant cerebrovascular pathology is present. The structural variation of vertebral artery could be related to its origin, length or course of the vessel[xi]. A certain number of individuals have their left vertebral artery directly originated from the aortic arch proximal to the origin of left subclavian artery, rather than from the vessel itself[xii]. This could create an imbalance between right and left sided circulation and an increased incidence of cerebrovascular event and therefore more vulnerable to form atheromatous plaque and aneurysm formation in view of higher turbulence flow. On the other hand, the anomalous origin was identified as an independent risk factor for arterial dissection. This could be related to its entrance to the cervical spine only at foramen transversarium of C4 and C5, producing a longer course that could be stretched and led to spontaneous dissection. In the event of trauma with co-existing arteriopathy, interpretation would be complicated and may imply different degree of liability to the inciting event.

It was also reported that a short extra-cranial vertebral artery loop segment, namely the portion between C2 vertebra to the dura, can theoretically render the individual to develop stress and eventual rupture due to displacement of foramina of C1 and C2 in atlanto-axial rotation upon blunt force trauma to the neck region[xiii]. Significant variation in length was noted between each of these different segments, for example, at C2 foramen, between C1 and C2, at C1 foramen and between C1 and foreman magnum. When applied in a daily medico-legal context this anatomical variant is however, difficult to be appreciated without ancillary radiological modalities.

Selected entities of abnormal origin of vertebral arteries[xi]:
Left Vertebral Artery

Arch	Between Left Common Carotid Artery and Left Subclavian Artery
	Behind Left common Carotid Artery
	Distal to Left Subclavian Artery
	Posterior to the origin of Left Subclavian Artery
Extra-Arch	Left External Carotid Artery
	Thyrocervical Trunk
	Carotid bulb
	Left Common Carotid Artery
Exotic position in Left Subclavian	From the base of Left Subclavian Artery in superior mediastinum
	Common trunk of Left Vertebral and Left Inferior Thyroid Artery
	Distal to Thyrocervical trunk

Right Vertebral Artery

Arch	Root of Right Subclavian Artery
	Distal to Left Subclavian Artery
	Between Right Common Carotid and Right Subclavian Artery
	Proximal to Left Subclavian Artery

Extra-arch	Right Common Carotid Artery
	Brachiocephalic trunk
	Descending Aorta
	Ascending Aorta
	Right External Carotid Artery
	Thyrocervical trunk
Exotic Position in Right Subclavian	Distal to Thyrocervical trunk
	Common trunk of Right Vertebral artery and Inferior Thyroid Artery

Dissection refers to tear in the wall of tortuous artery resulting in intramural haematoma and results in (a) stenosis if the layer between intima and media is involved; (b) formation of aneurysm[xiv] if media and adventitia is involved[xv]. It can occur either in the extra-cranial or intra-cranial segment of the vessel. Clinically it presents with stroke due to ischaemia of the posterior circulation by narrowed lumen or embolization from local thrombus; or subarachnoid haemorrhage if the aneurysm has ruptured. Combination of neurological deficits like lateral medullary (Wallenberg syndrome) and cerebellar infarctions are the presentations. Cord infarction denotes spinal arteries involvement. Dissection could also be a result of natural spontaneous event related to genetic causes of arteriopathy[xv], including Ehler-Danlos syndrome type IV, Marfan's syndrome, fibromuscular dysplasia[xvi], alpha-1 antitrypsin deficiency, homocystinaemia, angiolipomatosis, lentigenosis, autosomal polycystic disease and osteogenesis imperfecta type I[xvii]. It is an important cause of stroke to be considered in young patients and therefore has long term implications for family members. The site of rupture is postulated to be within the connective tissue or vasa vasorum of media, precipitated by movements involving hyperextension or rotation of neck. These could be associated with innocent daily activities which are not commonly perceived as trauma such as painting a ceiling, yoga, sneezing, vomiting, to anaesthetic procedures, etc.

It is worthwhile to mention that chiropractic manipulation was reported as a rare cause of vertebral arterial dissection[xv] [xviii]. It has an annual incidence rate was approximately 1 to 1.5 per 100,000. Interestingly there was a report of dissection after playing roller coaster with bilateral carotid and vertebral artery dissections[xix]. These were possibly related to sudden hypertension, hyperflexion and rotational neck movements by excessive gravitational force generated and stripping off the intima. Other recreational activities include trampoline use, amusement park rides and scuba diving.

Associated clinical risk factors for dissection include smoking, hypertension, use of oral contraceptives and migraine. Pregnancy and puerperium are also related to spontaneous vertebral artery dissections, in addition to usual involvement by aortic and coronary vessels[xx]. Preeclampsia, hormonal and vasoactive substances on the vessel walls, together with mechanical factors, such as Valsalva maneuvers during labour are possible explanations. A history of radiation to head and neck region weakening the vessel wall is a contributing factor.

Trauma is also a serious cause of fatal vertebral artery dissection apart from natural process. Significant hyperextension coupled with lateral flexion or rotational movement is implicated in the injury process by blunt force trauma towards the lateral aspect of neck at the skull base region. As mentioned, dissection could lead to vascular stenosis resulting in cerebral infarct[xxi] or subarachnoid haemorrhage if there is transmural rupture. Generally, if the dissection involves extracranial segment of the vertebral artery, e.g. C5 and C6 of the transverse segment, the result could be cerebral infarction complicating thrombosis. This is often exacerbated when the contralateral vessel is hypoplastic or has intrinsic arteriopathies. Death is often the sequelae of extensive cerebral and brainstem infarction.

Significant traumatic events such as motor vehicle accidents[xxii] [iv], including seat-belt injury with belt webbing[xxiii] for passengers[xxiv], high level or complicated falls[xxv], suicidal hanging can result in damage to the

cervical spine and vertebral artery. A component of whiplash injury as postulated mechanism of trauma has been reported[xxvi]. Accidental low-level fall from wheelchair presenting as C5 fracture with laceration of vertebral artery complicated by retropharyngeal haemorrhage has been reported[xxvii].

Massive basal subarachnoid haemorrhage related to traumatic vertebral artery dissection is a special presentation in forensic practice. While the more frequent site of rupture is the intracranial segment (V4) of the vessel, the extracranial segment, namely the extradural segment (V3) which the artery has penetrated the dura, can also produce extensive subarachnoid haemorrhage. The seemingly extracranial location of the bleeding resulting in massive intracranial bleeding has been discussed. It was believed that there exists a pressure difference between the cerebrospinal fluid and systolic blood pressure, allowing blood to track along nerve roots to the spinal subarachnoid space reaching the base of brain. This vulnerable arterial segment is often considered as the "weakest link" of the entire vessel. It is especially tortuous, while there is a decrease in thickness of media and elastic fiber extending from 1 cm extradurally to 0.5 cm beyond the point of penetration through the dura[xxviii]. Rotation and extension of head secondary to sudden awkward or unaccustomed neck movements during a traumatic event, is accompanied by a component of acceleration and declaration forces. All of these can result in stretching and narrowing, eventually rupturing the vessel by tensile and compressive stress[xxix]. A sudden exposure of vertebral artery to pressure between 150 and 250 mmHg upon occlusion with reverse flow may also be responsible for rupture, known as the water-hammer effect[xiii]. As the vessel is fixed at the site of foramen transversarium of atlas against the crescentic border of posterior atlanto-occipital membrane, this can cause either rupture of the intracranial or extracranial segment.

It goes without saying that identifying the site of trauma or the point of rupture is of paramount importance in medicolegal autopsies. However, this is often met with great difficulty due to its inaccessible anatomical location. Ikegaya had proposed the use of milk at injection medium in examining intracranial segment under direct observation during autopsy[xxx]. The extracranial segment is examined by en-bloc removal of the posterior neck structure, either via an anterior or posterior approach. The spine can be severed at or below C4 level by sawing and submitted for angiography and decalcification using formic or nitric acid. These methods are, however, often time consuming and tedious. Kim et al has proposed a method of removing the brain, spinal cord and vertebral arteries via posterior neck incision, accessing the spinal cord and visualizing the vessels after an inverted wedge of posterior occipital bone is removed. Furthermore, with the assistance of postmortem CT scanning and contrast injection upon cannulation of vertebral artery, it is also possible to identify the origin of subarachnoid hemorrhage due to aneurysm [xxxi] or other concomitant vascular injuries[xxxii] [xxxiii]. The results undergoing experimental trial in local pathology service are, so far promising.

According to Kim et al, we would recommend the following procedures for a practical examination of vertebral artery[xxxiv] [xxxv] [xxxvi]:

1. Adequate exposure of the posterior neck and upper trunk musculature by wide incision.
2. Dissection and removal of posterior neck muscle to the bony structures.
3. Remove the posterior laminae of upper cervical spine.
4. Remove an inverted wedge from the posterior bone just above the foramen magnum.
5. Incise the dura from the atlanto-occipital junction and upper cervical cord.
6. The spinal cord is pulled over to one side, cutting the dura surrounding the penetration portion of the vessel (V3).
7. The intracranial portion of the vessel is lifted and the extracranial portion is cut just below the dura.
8. The brain, spinal cord and dissected segments of vertebral arteries could be removed together and examined for lesion.

Concerning the laterality of injury[xxxvii], ipsilateral involvement is more common as the head is usually flexed in the direction away from the side of injury producing hyperextension of the ipsilateral vertebral artery. Isolated cases have been reported with contralateral rupture due to impact by a high-speed golf ball which resulted in flexion of head towards the same side with contralateral hyperextension.

Histologically nonspecific changes had been reported at the site of rupture in the absence of underlying vessel pathology[xxxviii]. These include minor focal subintimal fibrosis, focal disruption of internal elastic lamina and medial calcification. Special statins such as Masson trichrome, Movat Pentachrome, Elastic Masson-Goldner (EMG) and Phosphotungstic acid Haematoxylin (PTAH) are necessary[ix]. Ro et al has postulated morphological characteristics of traumatic vertebral dissection versus spontaneous rupture as below[xxxix]:

	Traumatic rupture	Spontaneous rupture
Macroscopic appearance	■ Longitudinal laceration	■ Fusiform aneurysm with longitudinal rupture
Histological findings		
At ruptured site		
Appearance **Adventitia** **Peripheral lesion**	■ Transmural arterial rupture ■ Not extended ■ Oblique tear of the intima and media	■ Arterial dissection ■ Extended ■ Intimal tear according to medial defect
Non-ruptured site		
Other findings	■ Small incomplete tears ■ Fragmentized internal elastic lamina	■ Previous non-ruptured dissection ■ Medial degeneration or defect

Role of Alcohol in Vertebral Rupture

The role of alcohol worth some elaboration in this devastating condition. During incapacitation there is impairment of neuromuscular coordination and musculature relaxation[ii], clinically reflected by a prolonged reaction time and diminished alertness[xl], rendering the artery prone to stretching. The effects of vasodilation and elevated blood pressure may also play a role[xxviii].

Public Health Implications

A knowledge of vertebral artery trauma does play a role in public health. The tragedy of Australian cricketer Philip Hughes refers to the death of a popular batsman in 2014. He was struck on the neck by a fast bouncer in a match on 25th November. Video footage captured the moment where he collapsed almost instantaneously and soon identified unilateral vertebral artery dissection as the culprit. Though he was wearing protective gear at the time of incident, it was insufficient to cover the impact site. He succumbed two days later at the age of 25 due to unsalvageable neurological damage. Hughes' death was shocking and prompted attention on the use of protective gear in subsequent contests.

Public health measures to reduce risk of vertebral artery injury in competitive sports, extracted from Saw et al[xli]

Strategy	
Primary	■ Screening for at risk individuals especially with likelihood of vasculopathy ■ Reduce likelihood of impact by reforming rules and player education and improvised skills
Secondary	■ Reduce the effect of impact to head and neck by personal protective equipment (helmet, cover area down to C2) ■ Reduce movement of neck by restrictive equipment
Tertiary	■ Improve early detection of vertebral artery dissection especially on cases with delayed symptoms for medical professionals, proper assessment and follow up of head and neck impacts, imaging techniques to detect small existing or healed lesions

On the other hand, a previous study on sudden infant death syndrome (SIDS) had reported that a possible explanation of infants being found dead unexpectedly in cot. It was postulated that in certain individuals with a small lateral mass of C1 and large foramen magnum, could result in unstable atlanto-occipital joint and C1 could therefore be inverted cranially and compress the vertebral artery, especially when the infant adopted a prone sleeping position, causing sudden demise[xlii].

Case vignette

Death due to vertebral artery rupture might sometimes be encountered tragically when the deceased sustained an "apparently benign" blunt impact, such as a fist punch[xliii] on the neck region. In 2018 the Court of First Instance had convicted an elderly male of manslaughter unanimously by jury by dangerous and unlawful act, sentenced to 5 years' imprisonment. Video footage depicted verbal exchanges between another elderly male due to trivial matters. Soon the deceased and the defendant engaged into physical contact with each other. The deceased kicked the defendant once and in return the defendant started to punch back. It was unclear about how many punches were inflicted but autopsy revealed only apparently minor injuries in the form of small lacerations and abrasions. During autopsy there were patchy contusion along the paraspinal muscles of the cervical vertebrae and strap muscles. There were also bruising along the adventitial tissues of right common carotid artery. Acute basal subarachnoid haemorrhage was present. There were minimal deep-seated injuries of the facial skeleton and the cranium was intact. Exploration of the V3 segment of vertebral artery showed a 4 mm longitudinal tear close to the dural penetration with blood infiltration. Histological analysis of the involved vessel showed no evidence of arteriopathy but intimal thickening with atheromatous changes were noticed. It appeared that one of the punches had resulted in acute rupture of left vertebral artery and he lost consciousness almost immediately. Toxicological analysis detected blood alcohol at a level of 20 mg/100 mL. The case was construed as involuntary manslaughter which the legal elements of unlawful homicide were committed without malice aforethought. It was a result of an unlawful act likely to cause bodily harm which is not grievous, i.e. the few punches were not expected to be lethal, at least from a layman's perspective, but had inadvertently resulted in a fatal outcome.

Conclusion

A forensic approach to vertebral artery trauma requires a comprehensive and systematic assessment that integrates detailed medical background, symptomatology, proper external and meticulous internal examinations, targeted imaging, and histopathological analysis. Recognizing the anatomy and evidence of vertebral artery trauma in a concealed location is crucial for accurate diagnosis of the entity, which in turn provide vital evidence in medico-legal investigations.

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