

Direct Damage to a Vertebral Artery Better Predicts a Vertebral Artery Injury than Elongation in Cervical Spine Dislocation

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Cervical spine dislocation and fracture of a transverse process are isolated risk factors for vertebral artery injuries (VAIs), which can cause a life-threatening ischemic stroke. Since *in vivo* experiments are not possible, it has not been unclear whether damage to or extension of vertebral arteries is more predictive of a VAI. To identify the imaging characteristics associated with VAI, we analyzed 36 vertebral arteries from 22 cervical spine dislocation patients who underwent computed tomography angiography (Aug. 2008-Dec. 2014). We evaluated (1) the posttraumatic elongation of the vertebral artery and (2) the presence of fracture involving the transverse foramen. VAI was found in 20 (56%) of the 36 vertebral arteries. The rate of residual shift (vertebral artery elongation) was not markedly different between the VAI and no-VAI groups. However, the rate of > 1 mm displacement into the foramen and that of fracture with gross displacement (≥ 2 mm) differed significantly between the groups. We found that greater displacement of fractured transverse processes with cervical spine dislocation was a risk factor for VAI. These results suggest that direct damage to the vertebral arteries by transverse process fragments is more likely to predict a VAI compared to elongation, even in cervical spine dislocation.

Key words: vertebral artery injury, cervical spine dislocation, CT angiography, transverse process, vertebral artery elongation

A vertebral artery injury (VAI) can occur in individuals who sustain blunt cervical trauma, which may lead to catastrophic sequelae including posterior circulation stroke and death [1]. In particular, cervical spine dislocation is known to be associated with a high risk of VAI [2-4] with a reported incidence of up to 75%. Over the past two decades, the importance of active screening in patients with blunt cervical trauma has been increasingly recognized. In addition, previous

studies demonstrated that several clinical and imaging factors including ankylosing spondylitis (AS)/diffuse idiopathic skeletal hyperostosis (DISH), occipitocervical dislocation, basilar skull fracture, and bony fragments displaced into the transverse foramen are associated with an increased risk of VAI [2]. However, the study subjects in those reports were highly heterogeneous with respect to the injury type and the severity of concomitant trauma [5-8]. With the limited number of patients presenting solely with cervical spine dislocation

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included in the prior reports [9], it has been unclear which imaging characteristics are the most predictive of VAI in the presence of cervical spine dislocation.

In this retrospective study, we focused on patients with cervical spine dislocation between C3 and C6, and we sought to identify the imaging characteristics associated with VAI by using thin-slice computed tomography (CT). We hypothesized that the post-traumatic elongation of the vertebral artery at the dislocation level (as assessed by a residual shift of the transverse foramina at the dislocation level) and the severity of transverse process fracture are predictive factors for VAI.

Patients and Methods

Patients and diagnosis. The study, retrospective analysis, was approved by the Tokyo Metropolitan Bokutoh Hospital institutional review board. We reviewed the clinical data of patients over 16 years of age who were admitted to any of our 3 institutions from August 2008 to December 2014. We defined cervical spine dislocation as facet subluxation, facet perch, facet dislocation, or locked facet with/without facet fracture [10]. Both unilateral and bilateral dislocation case series were extracted from our database. Dislocations with/without vertebral body fractures were included. Patients with AS, DISH, occipitocervical dislocation or basilar skull fracture were excluded from this study. The diagnosis of AS was based on the findings from a previous report [11], and the diagnosis of DISH was also made on the basis of the criteria established by Resnick and Niwayama [12].

We examined the radiographic parameters of cervical spine dislocation by using the patients' findings revealed by computed tomography angiography (CTA) as a screening tool [13] on admission or soon after the reduction of the dislocation. We graded the VAIs using the Biffi scale [14] (Table 1). We reviewed the patients' medical histories for any findings associated with vascular risk factors including vascular diseases, such as

hypertension, diabetes mellitus, myocardial infarction, stroke, and malignancy [15, 16]. The neurological outcomes were measured by board-certified orthopedic surgeons using the American Spinal Injury Association Impairment Scale (AIS) on admission and at the final follow-up.

Radiological measurement. To detect how the vertebral arteries were elongated or how they were damaged by transverse process fragments, we measured these factors in the CTA images as follows: As the first factor, we employed 'a distance factor' to quantify the residual shift of the vertebral arteries following the injury. The distance factor was originally used as a measure of vertebral artery tortuosity [17]. In the present study, we used the CT parasagittal images (Fig. 1).

Then, to evaluate the damage to the transverse

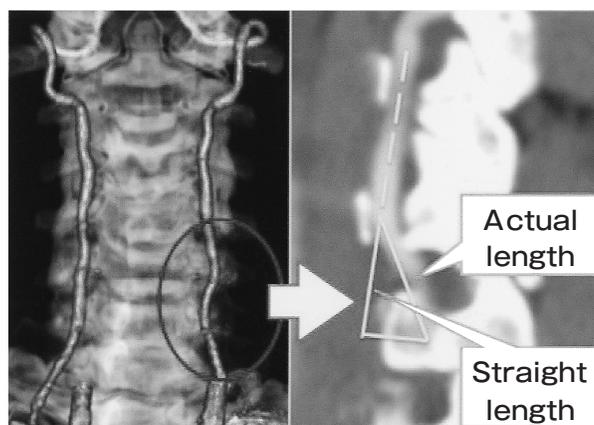


Fig. 1 Measurement of the distance factor. This image was obtained on CTA of a patient with C5/6 dislocation. Left: A 3D-CT image. Right: A parasagittal image of the dislocation level. To measure the straight length, we drew 2 lines. The first line connected two cranial transverse foramina above the dislocation and then was elongated to the caudal level. The second line was drawn at the center of 2 dislocated transverse foramina (actual length). The straight length was measured between the center of the dislocated cranial transverse foramina and the same height of the dislocated caudal transverse foramina. In this case, the measured distance factor = $[(\text{actual length} / \text{straight length} - 1) \times 100] = 7.1$.

Table 1 Biffi Scale

Grade I	Irregularity of the vessel wall, or a dissection/intramural hematoma with <25% luminal stenosis
Grade II	Intraluminal thrombus or raised intimal flap is visualized, or dissection/intramural hematoma with $\geq 25\%$ luminal narrowing
Grade III	Pseudoaneurysms
Grade IV	Vessel occlusions
Grade V	Transections

foramina, we analyzed the displacement of the fractured transverse process fragments as the second factor based on the morphology of a previous report [2]. Fractures around the transverse foramen were measured as the greatest displacement (mm) in the cervical spine CT scan (axial acquisition images, sagittal, or coronal reconstituted images). We analyzed the presence of multiple-level fractures of transverse processes, the presence of fractures involving the transverse foramen, displacement into the foramen >1 mm, and fractures with gross displacement (≥ 2 mm). The displacement referred to the distance between the largest fragment of the transverse process and the base of the transverse process (Fig. 2).

Treatment. For each of the patients, after primary treatment was administered based on the Advanced Trauma Life Support guidelines [18], a Halo-ring was connected and craniocervical traction was applied as a closed reduction [19]. If we were unable to stabilize the dislocations by this procedure, we transported the patient to an operation rooms and performed surgical reduction. The treatment of each VAI was determined by the surgeon in charge at the

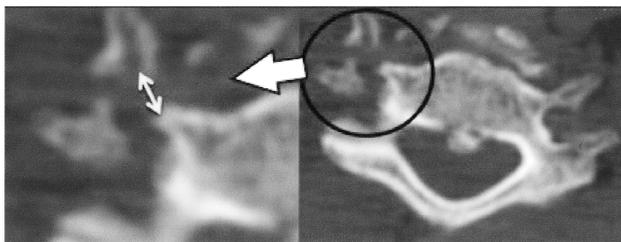


Fig. 2 Measurement of the distance of the displaced fractured transverse foramina. Right: An axial CT image of the cervical spine at the caudal dislocation level. Left: A zoomed-in version of the picture on the right. We analyzed the maximum distance between the base of the transverse process and the largest fragment.

time.

Statistical analysis. For the comparison of parameters between 2 or more groups, the chi-squared test was used for the categorical data, and the Mann-Whitney U-test was used for the continuous variables. For all of the statistical tests, a p -value <0.05 was considered significant. The Microsoft Excel software program was used for data management (ver. 14.5.7; Microsoft, Redmond, WA, USA).

Results

Based on the criteria described above, a total of 27 patients were diagnosed with cervical spine dislocation. Of these 27 patients, we excluded one vertebral artery anomaly patient. Among the remaining 26 patients (20 males and 6 females), there were 16 cases of unilateral dislocation and 10 cases of bilateral dislocation. The average age was 50.3 (range 17-71) years old. The average follow-up period was 24 (range 3-84) months, excluding the single patient who died 5 days after the trauma. Eight patients had a history of vascular risks, and hypertension was the most frequent, noted in five cases. VAI was found in 18 cases (69%); the no-VAI group was the other eight patients. Nine patients had American Spinal Injury Association Impairment Scale (AIS) scores of A-B, and the other 17 patients had AIS C-E scores on admission. The age, sex, laterality, background, incidence of transverse foramina fractures, and degree of spinal cord injuries (SCIs) did not differ significantly between the patients with and without VAI (Table 2).

The most frequent level of dislocation was the C5/6 segment in 15 patients (7 unilateral and 8 bilateral). The details are summarized in Table 3; there were no significant differences in the rate of VAI by dislocation

Table 2 Comparisons of the patients with and without VAI.

	Total (n = 26)	VAI+ (n = 18)	VAI- (n = 8)	P-value
Sex (male/female)	20/6	13/5	7/1	0.39
Age (yr)	50.4	53.7	43.0	*0.22
Unilateral/bilateral	16/10	11/7	5/3	0.95
Vascular risk (+/-)	8/18	6/12	2/6	0.67
Transverse foramen Fracture (+/-)	17/9	13/5	4/4	0.27
SCI (AIS A-B/C-E)	9/17	6/12	3/5	0.84

*By Mann-Whitney U-test (age); other parameters were assessed by chi-squared test. AIS: American Spinal Injury Association Impairment Scale; the score was obtained on admission. SCI indicates spinal cord injury.

Table 3 The relation between levels of dislocation and VAI.

Level of dislocation	VAI (n=18)	No VAI (n=8)	Total (n=26)
C2/3	0	1	1
C3/4	3	2	5
C4/5	4	1	5
C5/6	11	4	15

$p=0.42$. Chi-square value: 2.84. Degree of freedom; three.

Table 4 Transverse process fracture pattern associated with VAI

	Total	VAI (n=20)	No VAI (n=16)	<i>P</i> -value
Fracture involves transverse foramen	18	14 (70%)	4 (25%)	0.019
Displacement into foramen > 1 mm	11	10 (50%)	1 (6.3%)	0.014
Presence of gross fracture (> 2 mm displacement)	10	9 (45%)	1 (6.3%)	0.028
Multiple transverse process fractures	1	1 (5%)	0 (0%)	1

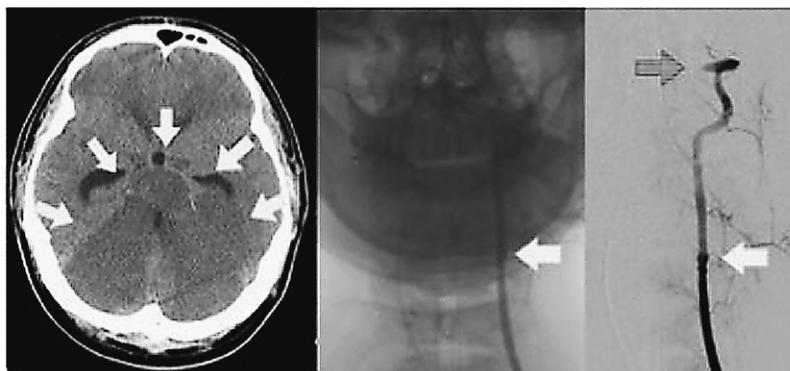


Fig. 3 Brain CT and DSA of a 25-year-old male patient who had C4/5 bilateral dislocation with a grade I vertebral artery injury. Brain CT showed ischemic stroke in his cerebellum and brainstem, and DSA showed a completed occluded basilar artery and a grade I VAI with intimal damage in his left artery.

level (Table 3).

We examined a total of 36 vertebral arteries, comprising 16 arteries from 16 patients with unilateral dislocation and 20 arteries from 10 patients with bilateral dislocation. VAI was observed in 20 of the 36 vertebral arteries (56%). There were 10 grade I-II injuries and 10 grade IV injuries. The average difference factor was 15.3 ± 9.5 in the no-VAI group and 14.4 ± 9.8 in the VAI group (\pm the standard deviation), without a significant difference ($p=0.95$).

Of the 36 vertebral artery routes, we found 18 fractures involving the transverse foramen, and a significant difference in the rate of these fractures was observed between the VAI group (70%) and no-VAI group (25%) ($p=0.019$). We also observed significant

differences between the VAI group and no-VAI group in the presence of fracture displacements into the transverse foramen over 1 mm (50% vs. 6.3%; $p=0.014$) and gross fractures (45% vs. 6.3%; $p=0.028$) (Table 4). All of the fractures were found in the caudal level of dislocation. Only one patient had a transverse process fracture at 2 levels at the dislocation site, and our case series did not contain any multilevel (more than 3 levels) transverse process fractures.

Only 2 of the 18 patients with VAI were treated for the VAI. One of these 2 patients was a 40-year-old male with a grade I VAI, treated by anticoagulation medications during reduction. The other patient was a 74-year-old male with a grade IV VAI treated by embolization before reduction, with no side effects.

One patient died due to basilar artery emboli. This 25-year-old male without any vascular risks was injured while play-fighting and was diagnosed with a C4/5 bilateral dislocation with the AIS score of A. He had no transverse process fracture. A grade I VAI was found in his left vertebral artery by CTA. At 19 h after the trauma, during craniocervical distraction without any anticoagulation medications, the patient suddenly lost consciousness. Brain CT showed an ischemic stroke in his cerebellum and brainstem, and digital subtraction angiography (DSA) showed that his basilar artery was totally occluded (Fig. 3). Intensive treatment was performed, but he died 5 days after the trauma.

Discussion

Cervical spine dislocation was reported to be an isolated risk factor for VAI [2]. Although many studies have evaluated the relationship between cervical spine fracture with and without cervical spine dislocation and VAI, only a few have examined the relationship between cervical spine dislocation and VAI [6]. Our present analysis revealed that 69% of the dislocation case series contained VAI, regardless of the patients' backgrounds. Prior reports showed a 21-75% incidence of VAI in cervical spine dislocation series [3,4]. Our surgical group actively performs CTA, which is recommended as a screening tool for VAI in the guidelines issued by the American Association of Neurological Surgeons [19], utilizing the modified Denver Screening Criteria [20]. The standard grading system used for VAIs was reported by Biffi and his colleagues, and they reported that Grade II and higher VAIs were associated with significant neurological morbidity and mortality [14]. However, the optimal management of these injuries remains heavily debated, and some groups have argued that every patient with a VAI can be treated considering their general condition [1,7,20].

Our results showed that the residual shift of the vertebral arteries' running after injury shown on CT was not associated with the occurrence of VAI, and that greater destruction of the transverse foramina was a predictive factor for VAI. We therefore determined that fracture displacement of ≥ 2 mm was a risk factor for VAI, and this measurement was easier to determine than detecting displacement into the foramen of > 1 mm, which was also reported to be an independent risk factor of VAI [2].

The pathophysiology of VAI includes occlusion, dissection, thrombo-embolism, intimal damage, pseudoaneurysm, rupture, arteriovenous fistula and transection [4]. Our hypothesis based on our present findings is that the fractures of the transverse processes contribute to direct vascular damage and that the vertebral artery endothelium damage then results in thrombo-embolic strokes; these phenomena were not attributed to arterial elongation. Dittrich reported that vertebral arterial elongation was not a distinct clinical marker of artery injury [21] and that most ischemic strokes caused by cerebrovascular injury are embolic in nature [22]. If our thrombo-embolism hypothesis is confirmed as correct, early reduction before the formation of a thrombus may be effective in preventing VAI. Indeed, Newton *et al.* reported that patients with cervical spine dislocation by low-velocity trauma who underwent closed reduction within 4 h of injury and recovered without VAI events [23].

Study limitation. There are several limitations to the present study. (1) The sample size was small, (2) CT might not reflect the maximum displacement of the dislocated cervical vertebra, and (3) we were unable to obtain compatible images from the same patients (e.g., CTA could not be performed before the injuries). First, considering the sample size, prior reports did not include the small numbers of dislocations given the rarity of cervical spine dislocation. For example, Miller's report [10] included 27 subluxation patients, and Lebl's report [2] included 15 dislocation patients. We focused on dislocation patients in the present study, and selection bias was accounted for by a multi-center setup.

The second and third study limitations are important because CT was performed with the patient in the supine position in the emergency room after transportation, and we were completely unable to rule out vertebral artery mutations or measure the maximum amount of dislocation immediately after the trauma. Although some vertebral artery abnormalities such as medial loop, fenestration, and erosion were already reported, Wakao found that there were only 2 patients with such anomalies out of 919 consecutive Japanese patients who underwent contrast-enhanced CT or CTA for reasons other than the evaluation of vertebral artery disease [24]. Vertebral artery diseases had not been identified in any of the patients in our series prior to the trauma. It is thus unlikely that the vertebral arteries had been elongated before the trauma.

Moreover, the cervical vertebral body migration at the center tended to be larger in the patients with a severe spinal cord injury compared to those without such an injury (5.7 mm vs. 4.4 mm, $p=0.27$) in our subanalysis. We suspect that the CT findings even in the supine position was associated with soft tissue damage including the spinal cord and vertebral artery, although the elongation of the vertebral artery shown by CT on admission could not completely reflect the dislocation during trauma.

In conclusion, greater destruction of the transverse foramina was a risk factor for VAI in patients with cervical spine dislocation. The residual shift of the vertebral artery elongation shown on CTA was not associated with VAI in patients with cervical spine dislocation. In such patients, CTA should be performed to document the extent of foraminal compromise to determine the risk factor for resultant thrombo-embolic events.

References

- Morton RP, Hanak BW, Levitt MR, Fink KR, Peterson EC, Vilela MD, Kim LJ and Chesnut RM: Blunt traumatic occlusion of the internal carotid and vertebral arteries. *J Neurosurg* (2014) 120: 1446–1450.
- Lebl DR, Bono CM, Velmahos G, Metkar U, Nguyen J and Harris MB: Vertebral artery injury associated with blunt cervical spine trauma: a multivariate regression analysis. *Spine (Phila Pa 1976)* (2013) 38: 1352–1361.
- Inamasu J and Guiot BH: Vertebral artery injury after blunt cervical trauma: an update. *Surg Neurol* (2006) 65: 245–246.
- Taneichi H, Suda K, Kajino T and Kaneda K: Traumatically induced vertebral artery occlusion associated with cervical spine injuries: prospective study using magnetic resonance angiography. *Spine (Phila Pa 1976)* (2005) 30: 1955–1962.
- Cothren CC, Moore EE, Biffi WL, Ciesla DJ, Ray CE Jr, Johnson JL, Moore JB and Burch JM: Cervical spine fracture patterns predictive of blunt vertebral artery injury. *J Trauma* (2003) 55: 811–813.
- Weller SJ, Rossitch E Jr and Malek AM: Detection of vertebral artery injury after cervical spine trauma using magnetic resonance angiography. *J Trauma* (1999) 46: 660–666.
- Mueller CA, Peters I, Podlogar M, Kovacs A, Urbach H, Schaller K, Schramm J and Kral T: Vertebral artery injuries following cervical spine trauma: a prospective observational study. *Eur Spine J* (2011) 20: 2202–2209.
- Miller PR, Fabian TC, Croce MA, Cagiannos C, Williams JS, Vang M, Qaisi WG, Felker RE and Timmons SD: Prospective screening for blunt cerebrovascular injuries: analysis of diagnostic modalities and outcomes. *Ann Surg* (2002) 236: 386–393.
- Louw JA, Mafoyane NA, Small B and Nesar CP: Occlusion of the vertebral artery in cervical spine dislocations. *J Bone Joint Surg Br* (1990) 72: 679–681.
- Dvorak MF, Fisher CG, Aarabi B, Harris MB, Hurbert RJ, Rampersaud YR, Vaccaro A, Harrop JS, Nockels RP, Madrazo IN, Schwartz D, Kwon BK, Zhao Y and Fehlings MG: Clinical outcomes of 90 isolated unilateral facet fractures, subluxations, and dislocations treated surgically and nonoperatively. *Spine (Phila Pa 1976)* (2007) 32: 3007–3013.
- Kubiak EN, Moskovich R, Errico TJ and Di Cesare PE: Orthopaedic management of ankylosing spondylitis. *J Am Acad Orthop Surg* (2005) 13: 267–278.
- Resnick D and Niwayama G: Diffuse idiopathic skeletal hyperostosis (DISH): ankylosing hyperostosis of Forestier and Rotes-Querol. *Diagn Bone Joint Disord Philadelphia: WB Saunders* (1995) pp 1463–1495.
- Grant GA, Mirza SK, Chapman JR, Winn HR, Newell DW, Jones DT and Grady MS: Risk of early closed reduction in cervical spine subluxation injuries. *J Neurosurg* (1999) 90: 13–18.
- Biffi WL, Moore EE, Offner PJ, Brega KE, Franciose RJ and Burch JM: Blunt carotid arterial injuries: implications of a new grading scale. *J Trauma* (1999) 47: 845–853.
- Wilkins JT, Ning H, Bery J, Zhao L, Dyer AR and Lloyd-Jones DM: Lifetime risk and years lived free of total cardiovascular disease. *JAMA* (2012) 308: 1795–1801.
- Walker AJ, Card TR, West J, Crooks C and Grainge MJ: Incidence of venous thromboembolism in patients with cancer—a cohort study using linked United Kingdom databases. *Eur J Cancer* (2013) 49: 1404–1413.
- Morris SA, Orbach DB, Geva T, Singh MN, Gauvreau K and Lacro RV: Increased vertebral artery tortuosity index is associated with adverse outcomes in children and young adults with connective tissue disorders. *Circulation* (2011) 124: 388–396.
- Committee on Trauma Advanced Trauma Life Support for Doctors ATLS, 8th ed., American College of Surgeons, Chicago (2008).
- Walters BC, Hadley MN, Hurlbert RJ, Aarabi B, Dhall SS, Gelb DE, Harrigan MR, Rozelle CJ, Ryken TC and Theodore N; American Association of Neurological Surgeons; Congress of Neurological Surgeons: Guidelines for the management of acute cervical spine and spinal cord injuries: 2013 update. *Neurosurgery* (2013) 60: 82–91.
- Ringer AJ, Matern E, Parikh S and Levine NB: Screening for blunt cerebrovascular injury: selection criteria for use of angiography. *J Neurosurg* (2010) 112: 1146–1149.
- Dittrich R, Nassenstein I, Harms S, Maintz D, Heindel W, Kuhlentäumer G and Ringelstein EB: Arterial elongation (“redundancy”) is not a feature of spontaneous cervical artery dissection. *J Neurol* (2011) 258: 250–254.
- Griessenauer CJ, Fleming JB, Richards BF, Cava LP, Curé JK, Younan DS, Zhao L, Alexandrov AV, Barlinn K, Taylor T and Harrigan MR: Timing and mechanism of ischemic stroke due to extracranial blunt traumatic cerebrovascular injury. *J Neurosurg* (2013) 118: 397–404.
- Newton D, England M, Doll H and Gardner BP: The case for early treatment of dislocations of the cervical spine with cord involvement sustained playing rugby. *J Bone Joint Surg Br* (2011) 93: 1646–1652.
- Wakao N, Takeuchi M, Kamiya M, Aoyama M, Hirasawa A, Sato K and Takayasu M: Variance of cervical vertebral artery measured by CT angiography and its influence on C7 pedicle anatomy. *Spine (Phila Pa 1976)* (2014) 39: 228–232.