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 dislocated 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...
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 foramen 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 VAI s using the Biffl 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 infraction, 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 = [(actual length / straight length – 1) x 100] = 7.1.]

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Irregularity of the vessel wall, or a dissection/intramural hematoma with &lt; 25% luminal stenosis</td>
</tr>
<tr>
<td>II</td>
<td>Intraruminal thrombus or raised intimal flap is visualized, or dissection/intramural hematoma with ≥ 25% luminal narrowing</td>
</tr>
<tr>
<td>III</td>
<td>Pseudoaneurysms</td>
</tr>
<tr>
<td>IV</td>
<td>Vessel occlusions</td>
</tr>
<tr>
<td>V</td>
<td>Transections</td>
</tr>
</tbody>
</table>

Table 1  Biffl Scale
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 administrated 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 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 level.

Table 2  Comparisons of the patients with and without VAI.

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

*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.
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 (± 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 VAI was reported by Biffl and his colleagues, and they reported that Grade II and higher VAIIs 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


