Original Article

Clinical characteristics and outcomes of patients with concomitant cervical spine trauma and vertebral artery injury: A literature review and retrospective analysis

ABSTRACT

Study Design: Retrospective review of a single institution cohort.

Objective: To assess the injury characteristics and outcomes in patients who suffered trauma to the cervical spine and vertebral artery injury (VAI).

Methods: This was a retrospective study of patients admitted to our trauma center with osseous or ligamentous cervical spine injury and VAI. Imaging findings were reviewed to classify the fracture types and fracture extension into transverse foramina was noted. Electronic medical records were reviewed to capture the mechanism of injury, discharge disposition, neurologic status, and mortality. Kaplan–Meier analysis was performed to determine the mean survival time and cumulative survival rate.

Results: Ultimately, 30 patients were included for the analysis. The mean age was 56 years old (range: 18–91 years). There were four major subgroups of cervical injuries: unilateral facet fractures (9 patients, 30%), occipital-cervical junction fractures (15 patients, 50%), translation or distraction injuries (3 patients, 10%), and injuries without extension into transverse foramina (20 patients, 67%). Left-sided VAIs were more common than right-sided (60% vs. 37%). Twelve patients (40%) initially presented with neurological symptoms. Nine patients (30%) died by final follow-up; the mean survival time for the cohort was 704.5 days (95% confidence interval: 440.1–968.9 days).

Conclusion: The laterality of facet fractures and fractures extending into the transverse foramina are associated with VAI sidedness. Various mechanisms may account for injury presentation, including rotation and hyperflexion. Given that patients may initially present without neurologic deficits, it is recommended that cervical trauma protocols integrate computed tomography angiography to reduce morbidity and mortality.

Keywords: Cervical spine, fractures, trauma, vertebral artery injury

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INTRODUCTION

Blunt force injuries to the cervical spine commonly lead to vertebral artery injuries (VAIs).[1] The reported incidence of VAIs following cervical trauma varies, with rates ranging from 0.53% to 39%.[2] Notably, cervical fractures extending into the transverse foramina, those involving facet subluxation, or fractures of the upper cervical spine (C1 to C3) have been associated with an increased risk of VAI.[3] VAIs can result in severe consequences such as ischemic attacks and strokes, which may be debilitating or fatal.[1,4] Mortality rates for VAIs have been estimated between 4% and 8%, underscoring the critical need for timely identification and intervention.[3,5]

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Early detection is particularly important because patients who initially present with normal neurological status can experience abrupt and significant decline due to latent or evolving vascular injuries.[6] Up to 30% of patients with VAIs may exhibit no neurological symptoms within the first 24 hours post-injury, highlighting the potential value of integrating vascular imaging studies into standard protocols for cervical spine trauma.[7]

Several diagnostic modalities are employed to assess VAIs, including computed tomography angiography (CTA), magnetic resonance angiography (MRA), and digital subtraction angiography (DSA).[8] Among these, CTA has increasingly become the preferred method due to its efficiency, high sensitivity and specificity, as well as cost-effectiveness.[9-12]

Nonetheless, despite the association between cervical spine trauma and VAIs, there is a relatively small body of the literature on the dynamics among the two. Further investigation into the clinical characteristics of this relationship is warranted. Thus, the aim of this retrospective study was to assess the impact of concomitant cervical trauma and VAI on patient morbidity and mortality, as well as to identify the major injury patterns associated with VAI. The findings may provide additional insight into the key factors influencing their relationship and highlight the importance of implementing standardized screening for VAI in cervical trauma protocols.

METHODS

Patient population

This retrospective study analyzed patients 16 years of age or older who were admitted to our urban Level I trauma center at an academic medical center between January 2020 and December 2023. This study received IRB approval. At our institution, a new protocol was instituted in January 2020 whereby all multisystem blunt injured adult patients receive empiric CTA scan of the cervical spine if they presented with injuries that warranted activation of the trauma team. All patients who received a CTA of the cervical spine via this mechanism were stratified to isolate those with a positive imaging finding. Using relevant ICD-10 codes, patients with evidence of blunt cerebrovascular injury (BCVI), i.e., a blunt injury to the carotid or vertebral artery, were selected for. Subsequently, a thorough review of CTA, MRA, and/or DSA reports for each patient was conducted to verify the presence of a VAI. Similarly, cervical computed tomography (CT) images were reviewed to confirm the presence of osseous or ligamentous cervical spine injuries. Any patients without both a VAI and a cervical spine injury were excluded. In total, 73 patients with abnormal cervical spine findings and BCVIs were identified. One patient was eliminated as they presented as a transfer from another institution and initial CT images were not available for review. Among the remaining 72 patients, 42 were excluded due to the absence of either a cervical spine injury or VAI upon review of clinical images and reports. Ultimately, 30 patients were included for final analysis.

Descriptive analysis

Basic demographic data including age and sex were extracted from the institutional trauma registry and electronic medical records. CT and magnetic resonance imaging images were reviewed and classified using the AO classification system, as well as briefly described. The presence of fracture extension into the transverse foramen, and laterality were likewise noted. Electronic medical records were reviewed to identify key characteristics of clinical presentation, including injury mechanism and presenting neurologic status, as well as to assess neurologic status at final follow-up or patient mortality if applicable. Lastly, Kaplan-Meier analysis was employed to provide estimates of mean survival time and cumulative survival rates for the cohort.

RESULTS

Demographics

The mean age was 56 years old (range: 18–91 years). Ten (33%) patients were female. The most common injury mechanism was motor vehicle collision (MVC) (33%), followed by falls from above ground level (23%) and ground-level falls (20%). Total follow-up ranged from 0 to 1153 days, with an average of 189 days.

Fracture/injury characteristics

All spine injuries were classified, described, and any operative intervention was recorded [Table 1]. Four subgroups were created using the common characteristics as detailed below. Representative case examples of patients from each subgroup and associated imaging findings are provided in Supplementary Figures 1-4.

Unilateral facet fractures subgroup

Nine patients (30%) had unilateral facet fractures [Table 2]. 7/9 patients in this subgroup (78%) had fractures involving the transverse foramen, and each of these 7 patients had VAI s with matching laterality. Furthermore, 8/9 (89%) patients in this subgroup had VAI which matched the laterality of the facet fracture.

Occipital-cervical junction fractures subgroup

Fifteen patients (50%) had fractures of the occipital-cervical junction (OCJ), defined as occurring between the occipital condyles and the C2–C3 disc space, inclusive [Table 2]. Dens

Table 1: Fracture characteristics of the study population

AO C-spine injury classification	Description of injury	Spine Sx	Fract of trasnsv foramen	VAI
C3 A1, C4 A1, N3	C3 and C4 compression fxs	C3–4 ACDF		R
C5–6, F2, N3	C5-6 R unilateral facet fx	C4–7 ACDF	R	R
C2 A, Nx	C2 type 2 dens fx		L	L
C7-T1, C, N4	C7-T1 fx/dx with bilateral perched facets	C5-T2 PSF, C7-T1 decompression		L
C5–6, F4, N1	C5–6 R unilateral facet fx		R	R
C5–6, F2, N0	C5–6 R unilateral facet fx	C5–6 ACDF	R	R
C5–6 B1, C6–7 B1, T1 A1, N0	C5–6, C6–7 posterior ligamentous injury			L
C2 C, N2	C2 type 2 dens fx with variant hangman's fx	Halo vest	B	R
C4–5, B3, N2	C4–5 extension type fracture in the setting of DISH	C2-T2 PSF, decompression, C4–5 ACDF		L
C7 A0, T1 A0, N0	C7, T1 SP fxs			R
C1 A, C2 B2, N0	C1 anterior arch, C2 type 2 odontoid	C1–3 PSF		R
C6–7 F2, N1	C6–7 L unilateral facet fx			L
C2 C, C4–5 F2, NX	C2 type 3 dens, C4–5 R unilateral facet fx			R
C4 A0, C7 A1, N0	C4 L TP fx, C7 compression fx			L
C4 A0, C5 A0, C6, A0, N0	C4–6 SP fxs			L
C7 A0, NX	C7 bilateral TP fxs			R
C2 C, C3 A0, N0	C2 type 3 dens fx, C3 TP fx	C1–4 PSF	R	L
C3–4 F2, N0	C3–4 L unilateral facet fx		L	L
C2–3 C, N4	C2–3 distraction injury			L
C1 A N0	C1 jefferson burst fx			L
C1 A, C2-3B, N0	C1 ant arch fx, C2–3 L unilateral facet fx		L	L
C1 A, C2 A, N0	C1 posterior arch fx, C2 type 1 dens fx			R
C2 B, N0	C2 hangmans fx		L	L
C5–6 C, N4	C5–6 hyperflexion injury		L	L
C5–6 B2, N3	C5–6 purely ligamentous injury with acute disc herniation	C5–6 ACDF		L
C1 A, C2 B, N0	C1 posterior arch fx, C2 type 2 dens fx		R	L
OC B, C5-6 F4, C6-7 F2, N3	Occipital condyle avulsion, C5–6 and C6–7 R unilateral facet fxs	C5–6 ACDF	L	L
C1 A, N0	C1 anterior arch fx			L
C2 B, N0	C2 hangmans fx		B	B
C2–3 F4, C3–4 F4, C5 C, N4	C2–3, C3–4 R unilateral facet fxs, C5 flexion teardrop fx	C3–7 ACDF, C5 corpectomy, C2-T2 PSF	R	R

VAI - Vertebral artery injury; R - Right; L - Left; B - Bilateral; PSF - Posterior spinal fusion; ACDF - Anterior cervical discectomy and fusion; DISH - Diffuse idiopathic skeletal hyperostosis

fractures of C2 were seen in 7/15 (47%) patients. 9/15 (60%) patients within this subgroup had fractures involving the transverse foramen. Notably, all three patients in this study who had transverse foramen fractures that did not correspond with VAI of the same laterality were members of the OCJ subgroup.

Translation or distraction injuries subgroup

Three patients (10%) had translation or distraction injuries [Table 2]. None of these patients had transverse foramen fractures and 2 of the 3 had complete spinal cord injuries.

No transverse foramen fracture subgroup

The final subgroup consisted of patients without transverse foramen fracture [Table 2]. This group included 20 (67%) patients. These patients presented with imaging findings consistent with axial loading or flexion/extension mechanisms.

Vertebral artery injury characteristics

There were more left-sided (60%) compared to right-sided (37%) VAIs, and only one example of bilateral VAI was identified. Thirty-three percent of patients had fractures involving the transverse foramen, with two examples of bilateral involvement. Of the 10 patients with transverse foramen fractures, 7 had VAIs with matching laterality. One additional patient had bilateral transverse foramen fractures but only unilateral VAI.

Neurologic injuries

At the time of presentation, 12 (40%) patients had a neurologic deficit [Supplementary Table 1], including 4 patients (13%) with complete spinal cord injuries. Of these 12 patients, 6 saw improvement of neurologic status at final follow-up. Only one patient (3%) suffered a neurologic decline which was attributable to their VAI, consisting of ataxia likely related to a cerebellar stroke which was persistent at the final follow-up.

Table 2: Fracture subgroups

Patient number	Description of injury	Transv foramen fx	VAI laterality
Unilateral facet fracture subgroup			
2	C5–6 R unilateral facet fx	R	R
5	C5–6 R unilateral facet fx	R	R
6	C5–6 R unilateral facet fx	R	R
12	C6–7 L unilateral facet fx		L
13	C2 type 3 dens, C4–5 R unilateral facet fx		R
18	C3–4 L unilateral facet fx	L	L
21	C1 ant arch fx, C2-3 L unilateral facet fx	L	L
27	Occipital condyle avulsion, C5–6 and C6–7 R unilateral facet fxs	L	L
30	C2–3, C3–4 R unilateral facet fxs, C5 flexion teardrop fx	R	R
Occipital-cervical junction subgroup			
3	C2 type 2 dens fx	L	L
8	C2 type 2 dens fx with variant hangman's fx	B	R
11	C1 anterior arch, C2 type 2 odontoid		R
13	C2 type 3 dens, C4–5 R unilateral facet fx		R
17	C2 type 3 dens fx, C3 TP fx	R	L
19	C2–3 distraction injury		L
20	C1 jefferson burst fx		L
21	C1 ant arch fx, C2–3 L unilateral facet fx	L	L
22	C1 posterior arch fx, C2 type 1 dens fx		R
23	C2 hangmans fx	L	L
26	C1 posterior arch fx, C2 type 2 dens fx	R	L
27	Occipital condyle avulsion, C5–6 and C6–7 R unilateral facet fxs	L	L
28	C1 anterior arch fx		L
29	C2 hangmans fx	B	B
30	C2–3, C3–4 R unilateral facet fxs, C5 flexion teardrop fx	R	R
Translation/distraction injury subgroup			
4	C7-T1 fx/dx with bilateral perched facets		L
9	C4–5 extension type fracture in the setting of DISH		L
19	C2–3 distraction injury		L
Fractures without transverse foramen involvement			
1	C3 and C4 compression fxs		R
4	C7-T1 fx/dx with bilateral perched facets		L
7	C5–6, C6–7 posterior ligamentous injury		L
9	C4–5 extension type fracture in setting of DISH		L
10	C7, T1 SP fxs		R
11	C1 anterior arch, C2 type 2 odontoid		R
12	C6–7 L unilateral facet fx		L
13	C2 type 3 dens, C4–5 R unilateral facet fx		R
14	C4 L TP fx, C7 compression fx		L
15	C4–6 SP fxs		L
16	C7 bilateral TP fxs		R
19	C2–3 distraction injury		L
20	C1 jefferson burst fx		L
22	C1 posterior arch fx, C2 type 1 dens fx		R
25	C5–6 purely ligamentous injury with acute disc herniation		L
28	C1 anterior arch fx		L

VAI - Vertebral artery injury; R - Right; L - Left; B - Bilateral

Clinical outcomes

The average injury severity score at initial presentation was 19.4, with a range of 4–75. The average intensive care unit length of stay was 18.9 days, with a range of 0.63–73.8 days. The average hospital length of stay was 16.7 days, with a range of 1–80 days. Half (15 out of the 30 patients) were discharged to home, which was the most common discharge disposition. The breakdown of discharge dispositions for this cohort is listed in Supplementary Table 2.

The mean survival time for the entire population was 704.5 days (95% confidence interval: 440.1–968.9 days). A cumulative survival curve is provided in Supplementary Figure 5. Nine patients (30%) were deceased at final follow-up. Among these nine patients, the average time of survival after injury was 348 days; however, seven survived 50 days or longer. One patient died a day after their injury, and another died 3 days after their injury.

DISCUSSION

While cervical spine trauma and VAI are commonly coincidental, the interplay between the two has not been well studied, although the consequences of misdiagnosis of VAI or of delayed treatment can be severe.[13] We conducted this retrospective analysis to understand the initial injury morphologies and outcomes associated with VAI to facilitate timely diagnosis and to anticipate the clinical course after these injuries. Our study found a close relationship between transverse foramen fracture and VAI, highlighting the unique importance of rotational injury mechanisms in causing VAI. We also noted a diverse array of clinical presentations, including both low- and high-energy injury mechanisms, along with a wide range of presenting neurological statuses, underscoring the difficulty of initial diagnosis and the importance of enhanced diagnostic protocols in the setting of cervical trauma.

Prior studies have demonstrated that fractures extending into the transverse foramina are strongly associated with VAIs.[14-17] In our cohort, 14 patients sustained a fracture extending into a foramen, and 2 of these patients had bilateral involvement. Of these 16 total foraminal fractures, 13 (81%) were accompanied by a VAI on the same side, suggesting a potential causal relationship between foraminal fracture and VAI. Bilateral VAI was rare (1/30, 3%) and only occurred in the setting of a C2 hangman fracture with bilateral extension into the transverse foramina, again demonstrating the close concordance between transverse foramina fracture and VAI. In the literature, bilateral VAIs are likewise considered to be uncommon; Temperley *et al*. conducted a systematic review that found that bilateral VAIs were only reported in 9.8% of studies analyzed.[2] Thus, it appears that the likelihood of bilateral VAI may not necessarily be dependent on magnitude of fracture energy, translation, and/or distraction; in this study, a C2 hangman fracture led to this particular injury, while higher-energy fracture patterns with greater translation and distraction failed to produce bilateral VAI. Interestingly, the incidence of unilateral facet fractures appears to be closely related to both transverse foramen fracture and VAI. Of the 9 patients with unilateral facet fractures, all but one had VAI with the same laterality. This finding parallels the work of Maki *et al*., who likewise demonstrated that laterality of the facet fracture coincided with the sidedness of VAI.[18]

Rotational mechanisms for VAI in cervical trauma have been suggested in the literature.[19] The unilateral predominance of VAI coupled with the strong association between VAI and unilateral facet fractures suggests a mechanism in which one vertebra rotates on top of another, overloading a facet and then fracturing it, which then allows rotational displacement of the vertebra relative to a subjacent vertebra. This displacement applies tension to the vertebral artery, which is trapped and kinked between adjacent transverse foramina that have moved relative to one another.[20] VAIs associated with translational injuries were much less frequent in our cohort, which likely is in part due to: a) a lower overall incidence of these injuries in general, and b) that rotational mechanisms are more likely to cause VAI. None of the patients in the translation/distraction subgroup had transverse foramen fractures, suggesting that the rotational mechanism, which leads to VAI through the transfer of energy through the wall of the transverse foramen, may not apply in this subgroup. Previously, Gupta *et al*. reported that translational and rotational injuries pooled together led to the highest incidence of VAI;[21] however, based on our findings, it appears that the rotational injuries may have contributed more significantly.

Another prominent injury pattern was OCJ fractures. Previous literature has identified that injuries to this region are associated with increased rates of VAI,[22] which may be attributable to the spine's relative hypermobility at this junction.[23] In our study, patients who suffered OCJ injury presented with morphologies suggestive of a rotational mechanism (i.e., unilateral facet fractures). However, this cohort also included injuries suggestive of hyperflexion/extension mechanisms (i.e., C2 Hangman fracture, C2 dens fracture), or axial loading mechanisms. Compared with the unilateral facet fracture subgroup, there was a less consistent relationship between transverse foramen fractures and VAI in the OCJ subgroup; most patients (9/15, 60%) either had transverse foramen fractures without VAI of corresponding laterality, or no transverse foramen fractures at all. One explanation for this may be the long course of the vertebral artery cranial to the C2 transverse foramen, along which the artery is not constrained within foramina.

We found a high prevalence of patients with neurologic injury in our study, with 40% of patients having some neurologic deficit at presentation, and 13% presenting with complete spinal cord injuries. Mortality was high (30%), and only 50% of patients were able to be discharged to their homes. Together, these data suggest that while a large subset of VAI is related to high-energy blunt trauma (53% of patients were involved in MVC or falls from above ground level), a substantial minority of VAI are related to lower-injury traumas such as ground-level falls (20%). Notably, only one patient (3%) suffered neurologic decline which could be ascribed to their VAI; this consisted of ataxia likely related to a cerebellar stroke. This relative paucity of symptomatic progression of VAI may be attributable to the prompt diagnosis resultant from the generalized CTA screening protocol at our institution, and underscores the importance of timely diagnosis in limiting severe impairment.[24-26] Given that it is not uncommon for patients with VAIs to present with no symptoms initially,[27] and that low-energy injury mechanisms may lead to BCVIs at comparable rates to high-energy mechanisms,[28] default BCVI screening may be warranted.

Our findings support the integration of routine CTA into the management protocols for patients with cervical trauma, regardless of initial neurological presentation or injury mechanism. Early and comprehensive imaging can facilitate timely intervention and potentially mitigate severe outcomes associated with VAIs;[29] notably, Leichtle *et al*. proposed that universal screening for BCVIs should be deployed for patients at risk for BCVI, regardless of age or injury mechanism.[30] Similarly, Biffl *et al*. reported that the use of inclusive screening criteria allowed for the effective identification of asymptomatic VAI.[31] Given the possibility of delayed neurological decline from initial presentation, it is critical for patients with cervical spine injuries to receive thorough and ongoing evaluation. However, while CTA can be efficacious in leading to timely identification of VAIs, it should be noted that imaging is associated with increased patient radiation exposure[30] and nephrotoxicity,[32] as well as potentially significant financial costs at scale.[33] Thus, the decision to institute default CTA screening into cervical trauma management is likely dependent on resource allocation, feasibility, and availability of alternative imaging modalities if deemed more appropriate. It is important to note that empiric CTA screening for BCVI at our institution uses the same contrast load and radiation exposure as the standard trauma CT series without image quality degradation anecdotally.

Several limitations must be acknowledged. The retrospective nature of this study may introduce selection bias and limit the ability to generalize findings across different populations. Our inclusion relied on ICD-10 codes, and patients with VAI diagnosis may have been missed if they did not have a corresponding code. Variations in imaging and treatment protocols across institutions could also impact the results. In addition, the relatively small sample size precluded a strong quantitative analysis; for example, the Kaplan–Meier analysis cumulative survival estimates were likely skewed by the high proportion of censored events. Thus, future research with larger, multicenter cohorts could provide more definitive insights.

This study underscores the importance and difficulty of early detection of VAI given varied clinical presentations and injury mechanisms. Future studies should investigate the effectiveness of various treatment strategies for VAIs and their impact on long-term outcomes. In addition, biomechanical studies may be useful in detailing the specific injury mechanisms underlying VAI.

CONCLUSION

This study highlights the intricate relationship between cervical spine injuries and VAIs, emphasizing the need for early diagnosis and treatment. Various mechanisms, including rotation, hyperflexion, and extension, may contribute to injury presentation. In our population of patients with VAIs diagnosed using generalized CTA screening, symptomatic progression of VAI was rare (3%). By incorporating routine CTA into standard care protocols for patients with cervical spine injuries, clinicians can improve the early identification of VAIs, ultimately enhancing patient outcomes. Our findings contribute to the understanding of these complex injuries and provide a foundation for future research aimed at refining care and reducing complications in this challenging patient population.

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Conflicts of interest
There are no conflicts of interest.

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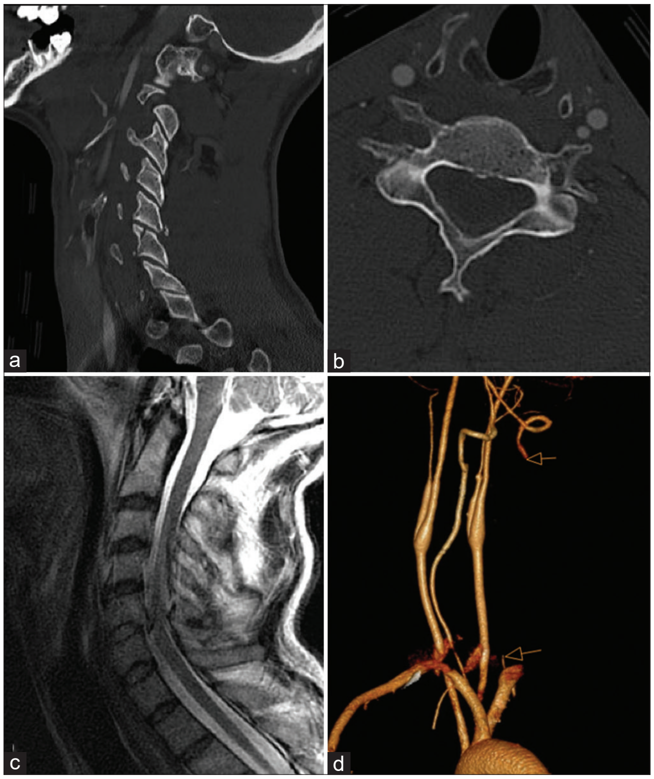
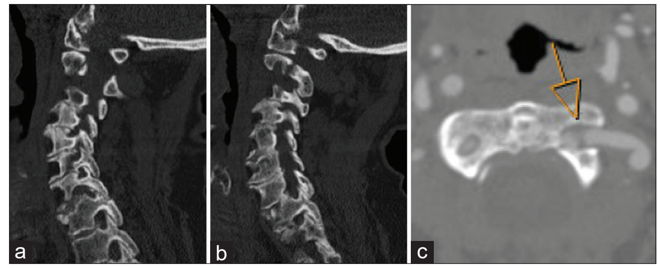
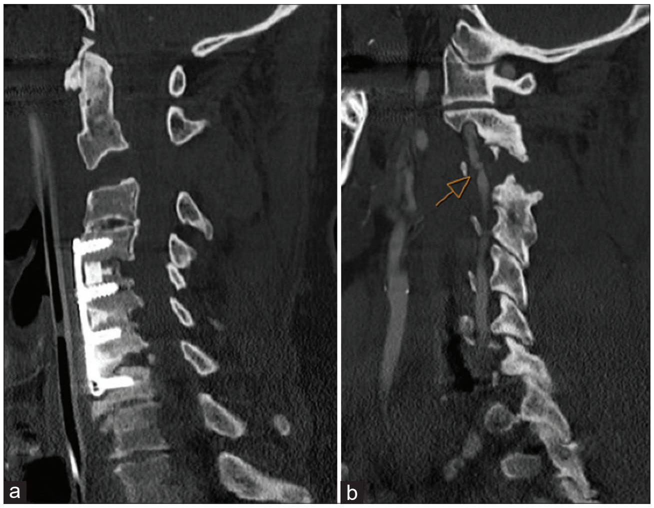


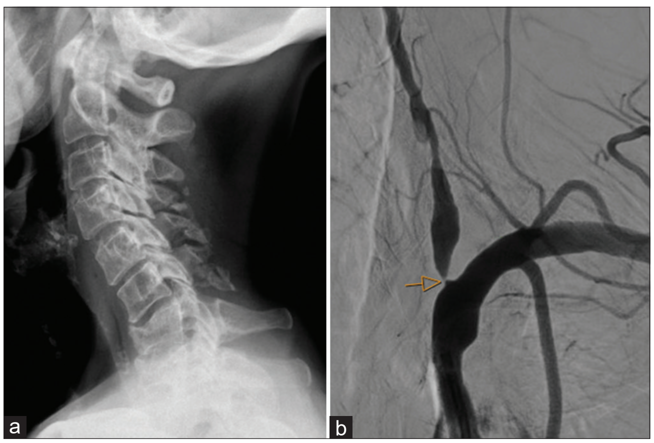
Supplementary Figure 1: Case 6, unilateral facet fracture. (a) Demonstrates C6 superior articular process fracture. (b) Fracture extends into the right transverse foramen. (c) MRI demonstrated acute intervertebral disc herniation resulting in severe central stenosis. (d) 3D reconstruction of computed tomography angiography demonstrates partial occlusion of the right vertebral artery beginning approximately 1 cm above its origin, with distal reconstitution (arrows)



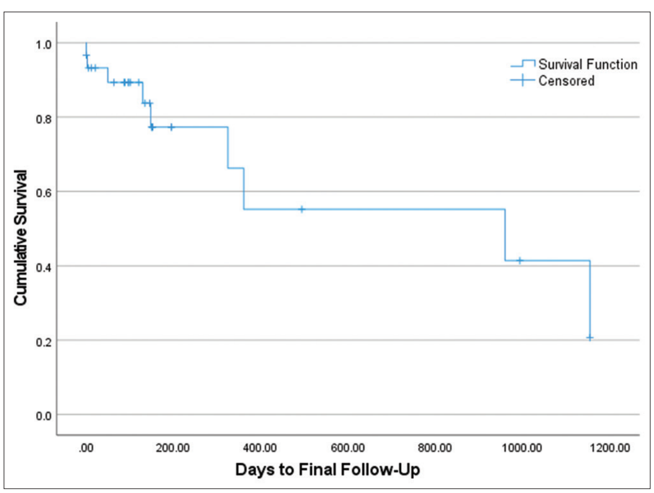
Supplementary Figure 2: Case 23, occipital-cervical junction injury. (a) Left parasagittal and (b) right parasagittal CT demonstrating bilateral pars interarticularis fractures. (c) Computed tomography angiography demonstrating focal left vertebral artery dissection (arrow) at level of C2 transverse foramen with partially decreased filling distally



Supplementary Figure 3: Case 19, translation/distraction injury. (a) Mid-sagittal and (b) left parasagittal CTs demonstrating C2-3 distraction injury with focal luminal irregularity (arrow) representing right vertebral artery dissection



Supplementary Figure 4: Case 15, no transverse foramen fracture. (a) Radiograph demonstrating C4-6 spinous process fractures, C7 and T1 compression factures. (b) Intraoperative digital subtraction angiography image demonstrating severe stenosis at origin of vertebral artery from left subclavian (arrow) consistent with dissection



Supplementary Figure 5: Kaplan–Meier survival curve of the study population

Supplementary Table 1: Characteristics of patients with C-spine injury and vertebral artery injury

Injury characteristics	Patient count (% of total population)
Neurologic injury	
No injury	15 (50)
Transient radiculopathy	2 (7)
Persistent radiculopathy	2 (7)
Partial cord injury	4 (13)
Complete cord injury	4 (13)
Unable to evaluate	3 (10)
Fracture into transverse foramen	10 (33)
Right	6 (20)
Left	6 (20)
Bilateral	2 (7)
VAI laterality	
Right	11 (37)
Left	18 (60)
Bilateral	1 (3)

VAI - Vertebral artery injury

Supplementary Table 2: Breakdown of discharge disposition

Discharge disposition	Patient count (percentage of total population)
Discharged to home	15 (50)
Inpatient rehabilitation	6 (20)
Subacute inpatient rehabilitation	5 (16.7)
Died after withdrawal of care	2 (6.7)
Other	2 (6.7)