Three Dimensional (3d) Computed Tomography Angiography (CTA) Study of Vertebral Artery (VA) Course at Craniovertebral Junction (CVJ) In Patients with CVJ Bony Pathology

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CERTIFICATE

This is to certify that the dissertation titled ―"Three dimensional computed tomography angiography study of vertebral artery course at craniovertebral junction in patients with CVJ bony pathology"is the bonafide original work of **Dr.Laxminadh Sivaraju** submitted in partial fulfilment of the rules and regulations, for Branch-II M.Ch. Neurosurgery, Part-II examination of the Tamil Nadu Dr. M.G.R. Medical University to be held in August 2013.

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Introduction

A normal VA has four segments, the first segment from the subclavian artery to the C6 transverse foramen, the second from C6 to C2 transverse foramen, the third segment from C2 to the foramen magnum and the fourth segment enters the cranium and forms basilar artery by uniting with the opposite VA. Third part of vertebral artery may have distorted course in cases of occipitalization of the atlas or if the anatomy of the C1 transverse foramen is distorted. Many authors have quantitatively studied the third part of the VA in the general population using dry bones and cadavers. [5,19,20,30,33,35,47] However, only a few have focussed on the VA in the presence of occipitalization of the atlas.[39, 48] In our study we focussed on the VA course at the C0-C1-C2 complex in all cases of congenital skeletal anomalies including occipitalization of atlas. We analysed variations of VA course and correlated it to the associated bony anomalies.

Literature review

The occipital bone encircling the foramen magnum, atlas and the axis vertebrae are together termed as the "craniovertebral junction" (CVJ). According to Gladstone and Erickson-Powell the first anatomic description of manifestations of occipital vertebrae was given by Meckle in 1815. The radiologic study on basilar invagination by Chamberlain in 1932 was a mile stone in understanding the clinical significance of craniovertebral junction anomalies. The same individual may have a wide range of congenital anomalies of craniovertebral junction comprising both the osseous and neural structures. The type and extent of abnormality can be assessed by CVJ craniometry including the Chamberlain line, Mc Gregor line, Mc Rae's foramen magnum line, Fishgold bimastoid line, Wackeheim clivus baseline, Welcher basal angle. [39]

Craniovertebral junction developmental anatomy (4^{th} week to 58 days)

Endochondral ossification results in formation of bony cranial base. By the end of fourth week of gestation, forty two somites are formed. At this point of gestation there are 4 occipital somites, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 8 to 10 sacrococcygeal pairs. Each somite differentiates into an outer dermatome, an inner myotome and a medial sclerotome. In this process the superior half of one sclerotome unites with lower half of its adjacent one and forms the vertebral body. However, the occipital bone and the posterior half of the foramen magnum are formed by the fusion of first four sclerotomes.

The basiocciput is formed by the first two occipital sclerotomes and the exoccipital bone formed by the third. The fourth one is the cardinal sclerotome also known as proatlas. The hypocentrum of the proatlas gives rise to the anterior tubercle of the clivus. It forms the apical cap of the dens and the apical ligament from the centrum. The neural arch component of the proatlas is divided into rostral ventral segment and a caudal dorsal segment. The ventral segment forms the anterior border of the foramen magnum, occipital condyle and the midline third occipital condyle. The caudal division of the proatlas gives rise to lateral atlantal masses and the superior portion of the posterior arch of atlas. Thus the axial zones of the proatlas become the basion and the lateral zones become occipital condyle and opisthion of the foramen magnum. The lower half of the posterior of the C1 arch is formed from the neural arch of the first spinal sclerotome and its hypocentrum forms the anterior arch of the atlas.[24,25,32]

The dens develops from the centrum of the first spinal sclerotome. The centrum of the second spinal sclerotome forms the axis body and its neural arch forms the facets and the posterior arch of the axis vertebra. At birth a cartilaginous band separates the base of the axis from the dens, so, the dens does not fuse with the base of the second cervical vertebra.[24]

Occipitalization of Atlas: It is also known as atlantooccipital assimilation and results from the failure of segmentation between the fourth occipital sclerotome and the first spinal sclerotome. It may be unilateral, segmental, focal or bilateral. It is often seen in association with other anomalies such as Klippel-Feil syndrome.[24] Congenital fusion of the atlas with the occiput is one of the most common anomalies of the CVJ with a prevalence rate of 0.08% to 2.8% in the general population.[32] The occipitalization of the atlas spans from complete assimilation of the atlas into the occiput to distinct bony connections between these two.[32] Gholve et al[32] retrospectively studied images (CT, MRI and X-rays) of thirty children who diagnosed as having occipitalization of atlas. Three fusion zones were described by them. Zone 1- involves the atlantal arch of atlas in front of the lateral masses. Zone 2 – involves the lateral masses and zone 3 involves the posterior arch of atlas.

The third occipital condyle: The hypochordal bows (hypocentrum) are mesenchymal condensations ventral to the notochord.[28] In human beings only the hypocentrum of the proatlas and first spinal sclerotome persist. As said above the hypocentrum of the proatlas forms a small midline osseous tubercle of the clivus. Occasionally this tubercle may become a bony structure distinct from the basioccipital bone. If the entire tubercle persists, it is known as a pre-basioccipital arch, if only the paramedian arch persists, two elevations protrude downwards from the clivus, termed as basilar processes. If the median portion of this tubercle persists and forms a prominent bone spur it may cause neural compression and is termed as a median or third occipital condyle (condyles tertius).

VA at craniovertebral junction

The VA along with the internal carotid artery is one of the two principle arteries which supply the brain. It arises from the posterosuperior aspect of the first part of the subclavian artery near its commencement. It is divided into four parts.

I^st^ part: It extends from the origin of the artery to the transverse process of the sixth cervical vertebra.

II^nd^ part: It runs through the transverse foramina of the upper six cervical vertebrae. Its course is vertical up to the axis vertebra.

III^rd^ part: It emerges from the foramen transversarium of the C1 and winds posteromedially dorsal to the lateral mass of the atlas. It runs medially lying on the posterior aspect of the atlas, enters the spinal canal by piercing the dura and then courses superiorly to enter the cranium and forms the fourth part.[48]

Observations from cadaveric studies

Goel et al[3] studied ten adult cadaveric specimens and 10 adult dry cadaveric C1 and C2 bones. They divided the VA into three segments at the C1/C2 level. The segment of the artery from C3 transverse process to C2 transverse process was described as the V1 segment and that from C2 transverse process to C1 transverse process was described as V2 segment. In this segment they found that the VA passes from the transverse process of the C2 vertebra and makes an initial lateral bend and courses superiorly running anterior to the roots of the C2 ganglion. It gives a large muscular branch and a small branch that sometimes runs into the spinal canal. The segment of the artery after its exit from the transverse foramen of C1 to its entry into the spinal canal was called the V3 segment.[3]

In its V3 segment, the VA takes a 90^0 posterior loop and turns medially to occupy in the groove on the superior surface of the posterior arch of the atlas. The distance between the most medial extension of the VA and the medial border of the VA groove on the outer cortex of the posterior arch of the atlas ranged from 2.1 mm to 5.2 mm (average 4.24 mm)

The VA does not fill the entire groove on the inferior surface of the superior articular facet of axis vertebra or over the posterior arch of the atlas. They calculated the occupancy ratio of the VA at the C2 superior facet by measuring the ratio of diameter of the VA to the oblique width of the bony groove. It occupies on an average only 79% of the groove of the superior facet of C2. The occupancy ratio over the posterior arch of atlas was calculated between the breadth of the bony groove and the diameter of the artery in that point. The ratio was about 57% of the groove over the posterior arch of the atlas. [3] By these observations the authors concluded that the VA did not fill the entire groove and the unoccupied place serves as a buffer space to the artery in the extreme neck movements.

Microsurgical anatomy of VA over the posterior arch of atlas

Tarik et al[47]examined the microvascular anatomy of the atlantal part of the VA (V3 segment according to Goel et al[3] in 14 cadaveric specimens having no features of craniovertebral junction problems and divided it into five segments:

Foraminal segment: The VA after entry the C1 transverse foramen run in a vertical direction and just after its exit from the C1 transverse foramen, it changes its course posteriorly and run in the sagittal plane. From point of entry to C1 transverse foramen to the point of direction change from vertical to posterior in the sagittal plane is called as foraminal segment.

Sagittal segment: After changing its course to posteriorly again it turns transversely above the C1 posterior arch. This region of the artery i.e. from the end of the first segment to the change of the course from the sagittal to transverse in the horizontal plane above the posterior arch of the atlas is called as sagittal segment.

Transverse segment: This part runs in the transverse groove above the C1 posterior arch. It may be arched or straight course. This part of the artery related anteriorly to the lateral mass of the C1. This is called as transverse segment. This segment ends where the artery changes it direction from transverse to upward at the medial side of the lateral mass of the atlas and occipital condyle.

Medial condylar segment: This segment runs upward and medially and enters the dura at the lateral aspect of the foramen magnum.

Dural segment: At the dural entry point the dura forms a sheath around the VA. This segment is called as dural segment. The authors measured the distance between the point of dural entry and the midline of the atlantooccipital dura. It is 16.8 mm (range 10-19.5mm).

They also observed the following branches at atlantal part of VA**:** [47]

Radiculomuscular branch: Originates just at the point of entry of the VA to the C1 transverse foramen. It travels medially to the atlantoaxial joint anteriorly and C2 nerve inferiorly.

Muscular branch: It arises above the C1 posterior arch and directs posterosuperiorly and medially.

Posterior meningeal artery: Distal to the muscular branch the VA gives posterior meningeal artery from the posteromedial aspect. It runs a tortuous course to enter the dura. The point of origin of this artery was 7-11 mm proximal to the point of dural entry of VA.

Posterior spinal artery: It originates at the posteromedial part of the VA at the point of the dural entry.

They also observed that the VA was encircled by a plexus of veins, continuous with the condylar emissary vein above and with veins below the C1 posterior arch. They noticed the vertebral arteries were frequently asymmetric and the average diameter on the right side was 3.9 mm and on the left side was 4 mm.

Description of VA anomalies at the craniovertebral junction (CVJ) from angiographic studies:

These can be divided into Extraosseous and Intraosseous.

Extraosseous Anomalies**:** In a review of the vertebral angiograms of 300 patients with a normal craniovertebral junction, Tokuda et al[49] in 1985 reported 3 types of extraosseous VA anomalies (Table 1).

1. Persistent first intersegmental artery (C2 segmental type of the VA): Tokuda et al[49] reported 2 cases in which the VA entered the dura below C1 (Figure 1). This anomaly was termed as 'C2 segmental type of the VA" .[49] In this type the VA turns posteromedially after its exit from the C2 transverse foramen and enters the spinal canal between C1 and C2 not passing through the C1 transverse foramen. It is a phenomenon in which the VA passes out the transverse foramen of C2 and then traverses under the posterior arch of the atlas instead of following its normal course through the transverse foramen of the atlas. Sato et al [36] found such an anomaly in vertebral angiograms of 10 cases among 1430 cases over a10 year duration. In the same paper they reported two cases of this anomaly based on MRI and CT scans in 1994. In one case the ipsilateral transverse foramen of the atlas was poorly developed. However they did not comment on any other associated bony anomalies. Apart from the case reported by Francois Vincentelli et al[8] five more cases were reported prior to Sato et al[36] (1994) had no symptoms or signs, three were identified by angiography and two were identified at autopsy.[36]

2. Fenestration of VA (Figure 1): VA divides into two after exiting from the C2 transverse foramen. One half runs as usual. The other half enters the spinal canal between C1 and C2 and joins the earlier at the cranial side of C1. There have been more than 40 previous reports in Japan alone on fenestration of the VA. [36] This anomaly can be seen in cerebral angiograms with an incidence of 0.3 to 2.0%.[36]

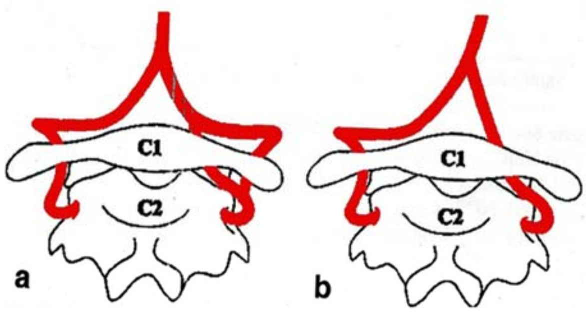


Fig 1: Schematic drawings of the anomalous courses of the left VA at the CVJ. A. Fenestration and B. Persistent first intersegmental VA. [53]

3. Extracranial origin of posterior inferior cerebellar artery: In this type the posterior inferior cerebellar artery originates from the VA between C1-C2 and enters the spinal canal from the caudal side of the C1.

ANOMALY/AUTHOR	PISA	FENESTRATION	PICA
J. T. Hong[21]	4. 4	0. 6	0. 2
Tokuda[54]	0. 67	1. 0	0. 67
Sato[42]	0. 6	0. 24	0. 36

Table 1. Incidence of the VA anomalies without bony anomalies according to various authors

Embryology of VA in correlation with craniovertebral junction bony development and its relevance with the anomalous course:

The cause of VA anomalies is thought to lie in the developmental process of the vertebrobasilar arterial system.[36] These anatomical variations of the VA can be explained by its embryological development.[52]

In the initial stage of development there are two aortic trunks (ventral and dorsal aorta). These evolve to form the carotid system, two arterial channels ventral to the rhombencephalon, one on each side of the midline and the ventral longitudinal arteries. This longitudinal arterial system gives origin to the vertebral artery, the basilar trunk and the spinal artery.[4] At Padget's stage 3 (embryo of 7-12 mm, 32 days) the VA begins to develop from the transverse anastomoses among the cervical segmental arteries. At Padget's stage 4 (12-14mm, 35 days), the primitive VA is formed.[8] During the sixth to eighth weeks of gestation, a certain number of longitudinal anastomotic channels are formed between these segmental arteries which eventually become the VA. Ultimately, the proximal connections of the intersegmental arteries to the dorsal aorta regress except for the sixth intersegmental artery, which becomes the adult subclavian artery. Hence, the definitive VA takes form through a series of longitudinal anastomoses linking the first 6 cervical intersegmental arteries from the subclavian artery to the craniocervical junction.[4, 38] Among these segmental arteries if the second dorsal segmental branch replaces the first, the vertebral artery may enter the dura below C1 without passing through the C1 transverse foramen. If it fails to retrogress, duplication of the VA may occur above and below C1.[49]

It is appropriate to remember that forty two somites are already formed and the basiocciput and exoccipitals are already developed by the end of fourth week of gestation.[55] Each segmental artery relates to the reconstructed definitive vertebrae formed from the upper and lower halves of the adjacent two embryonic sclerotomes, whereas its longitudinal anastomosis which forms the VA does not occur before this recombination stage. Possibly, failure of reconstruction of the embryonic sclerotome is associated with abnormal development of the segmental arteries.[49] By 53 days of gestation vertebrobasilar system is well developed. But the foramina for the vertebral arteries in C1 and C2 are simply grooves at 45 days of gestation. The vertebral arteries run vertically in these grooves. The vertebral foramina fully develop by 58 days of gestation.[55] So, when there is incomplete development of the cervical process, the VA which develops prior to this may also be underdeveloped. [36]

To summarise the above observations: The formation of the vertebrae occurs prior to the formation of the VA and it is followed by formation of the transverse foramina.

In one survey the Tokuda et al [49] noticed C 2 segmental type of anomaly in 4 cases among 21 patients with bony abnormalities like atlantoaxial dislocation, basilar invagination, occipitalization of atlas, Klippel-Feil syndrome at the craniovertebral junction. 36.4% incidence of anomalous VA in cases with bony anomalies like os odontoideum and hypoplastic odontoid at CVJ was reported by Yamazaki et al. [52] They observed that the C2 segmental type of the VA is often associated with occipitalization of the atlas or Klippel-Feil syndrome which has been described as failure of segmentation and rearrangement of the embryonic sclerotome.[52]

The intracranial entrance of VA in craniovertebral junction with occipitalization of the atlas:

Shenglin Wang et al[39] studied the course of VA in craniovertebral junction in 36 patients with occipitalization of atlas with 3-dimensional computed tomography angiography. They found four types of entry after analyzing seventy two vertebral arteries that are described in Table 2.

Type 1	Type 2	Type 3	Type 4
The VA enters below the occipitalized C1 posterior arch and the lateral mass. It was found in 6 (8.3%) arteries.	The VA goes into the spinal canal below the occipitalized C1 posterior arch, but posterior to the occipitalized C1 lateral mass. It was found in 18 (25%) arteries.	Passes through the transverse foramen of the atlas and enters an osseous foramen created between the fused atlas and occiput. It was found in 44 (61.1%) arteries.	The VA is absent on one side. It was found in 4 (5.6%) arteries.

Table 2: Shenglin Wang et al[45] The intracranial entrance of VA in craniovertebral junction with occipitalization of the atlas.

Tubbs et al[48] studied the intracranial entrance of the atlantal segment of the VA in five adult human crania with occipitalization of the atlas. The right and left lateral masses and anterior arch of the atlas were fused with occiput in all the specimens. In one specimen the posterior hemiarch of the left was not fused with the occiput and in other a rudimentary posterior hemiarch of the right was not fused with the occiput. Except in the two specimens in which the posterior hemiarch was not fused, the anomalous pathway of the VA was found. This abnormal pathway involved an osseous foramen created between the fused atlas and occipital bone. The authors observed the normal course in these two cases in which the posterior arch of the atlas was not fused with the occiput. However these authors did not mention about persistent intersegmental artery or fenestration.

Posterolateral protrusion of the VA over the posterior arch of the atlas (redundant loop): As described earlier after exiting the transverse foramen of C1, the VA courses posteromedially on the upper surface of the posterior arch of the atlas and turns abruptly in the anterior direction to enter the foramen magnum. Literature describes the VA coursing close to the superior articular facet of C-1 and the posterior arch of atlas. After exiting from the C1 transverse foramen the VA runs posterolaterally and then makes an anteromedial turn to cross over the superior surface of the posterior arch. These directional changes produce a posterolateral protrusion of the VA. Yamaguchi et al[37] quantitatively measured the maximum length of the perpendicular line drawn from the outer surface of the VA to the outer surface of the posterior arch of the atlas. They reviewed the 3D CT angiography images of 133 patients with various cranial and cervical diseases excluding patients with craniovertebral junction anomalies. They found on the right side it ranges from 1.39 mm to 14.10 mm and on the left side 1.44 mm to 13.65 mm and there was no difference in the age group. The mean distance on the right side was 6.73 and on the left side was 6.8 mm. The distance between the most medial extension of the VA and the medial border of the VA groove on the outer cortex of the posterior arch of the atlas ranged from 2.1 mm to 5.2 mm (average 4.24 mm).

Asymmetry of the vertebral arteries [3, 47]

The vertebral arteries are frequently asymmetric. Sometimes the minor VA is too small to be detected by angiography, and it may end in the posterior inferior cerebellar artery. If this minor VA ends in the basilar trunk it is termed as hypoplastic; if it is not connected to the basilar artery it is termed as atretic. Sometimes the artery may be completely absent.

Hong et al [15] reported a dominant right VA in 9. 8% and left dominant in 22.3%. These authors considered one side is dominant when its diameter was more than twice that of the other side. Then the other side was labelled as hypoplastic. 12% of unilateral hypoplastic artery was reported by Sanelli et al[35] and in these cases one or both may terminate in as a PICA. Touboul et al[52] reported the rate of VA hypoplasia was 6% in 50 healthy subjects. Yamazaki et al[52] found that 5 cases (6% of 31 cases) had a dominancy of the unilateral VA. According to Moftakhar et al[34], right was dominant in 22.4% and left was dominant in 46.7%.

The intraosseous anomalies

Yamazaki et al [52] used the term intraosseous anomaly to describe the VA when it was unusually shifted medially, posteriorly or cranially at the isthmus of C2 vertebra. It is also called “high riding VA”. In this condition the width and height of the C2 pars interarticularis is less than 5 mm and internal height is less than 2 mm. C2 pars interarticularis height is the distance from the superior surface of the pars interarticularis to the inferior surface. The internal height of C2 lateral mass is measured from the midpoint of the superior facet to the nearest point on the surface of the lateral mass or roof of the vertebral groove. [20,22,30] The VA makes an acute lateral bend just under the superior articular facet of the axis in approximately 80% of individuals. If this bending point is too medial or too posterior and / or too high, the height and / or the width of the isthmus of the axis will be narrowed and this condition is called as a high – riding VA.[30]

The anatomical features of the VA groove have been a key point of many recent studies. The VA groove is the hollow within the anterolateral wall of the superior facet of the axis that contains the superolateral turn of the VA as it exits the C2 transverse foramen. The clinical significance of the groove is that it potentially narrows the pathway of both the C2 pars interarticularis and the pedicle and may rule out screw placements. Mandel[22] et al measured C2 isthmus width and height in each specimen and concluded that placing a 3. 5 mm screw in patients with an isthmus width or height of less than 5 mm is technically difficult and that there is risk for VA injury.

In anatomic studies, Madawi et al[19] studied 50 dry specimens of C2 and reported that the thinning of the internal height of the lateral mass and the pedicle width was present in 22% them. Mandel et al[22] examined 205 cadaveric C2 vertebral bodies using CT measurements and concluded that approximately 10% of them may be at risk for VA injury with the placement of C1-C2 transarticular screws because of the narrowed C2 isthmus.

In a clinical study Song et al[42] analyzed 109 consecutive patients who underwent to C1-C2 transarticular screw fixation and reported that 13 cases (11.9%) had a unilateral narrow C2 isthmus and regarded this anomaly as contraindication for screw insertion. Yamazaki et al[52] found that 5 of 31 cases (16.1%) were diagnosed to have unilateral high-riding VA. Regarding the incidence of VA injury at the C1-C2 transarticular screw placement, a massive survey (on 2,492 screws in 1,318 patients) showed that the risk of VA injury was 4.1% per patient, the risk of neurological deficit from VA injury was 0.2%

per patient and the mortality rate was 0.1% per patient.[54] There have been several reports of VA injury as a complication of the C1–C2 transarticular screw fixation, including arteriovenous plexus fistula, occlusion, narrowing, or dissection of the VA, which could lead to transient ischemic attacks, stroke, or death. With preoperative three-dimensional CTA, we can precisely identify the anomalous VA, predict the risk of VA injury before surgery, and reduce the risk of intraoperative VA injury in advance.[52]

CT angiography

Computed tomography angiography (CTA) is a specialized X-ray that examines blood flow in arteries when they are filled with a contrast material (a substance that makes the blood vessels show on an X-ray). Computed tomography (CT) uses a sophisticated machine to take X-rays from many different views, producing detailed two-dimensional images that can be combined by a computer to form three-dimensional images. CT angiogram is the novel and popular study in diagnosing the various pathologies of cervical spine and craniovertebral junction. Patients tolerate the procedure well as it is non-invasive.

Aims & Objectives

Aim of the study: To document the incidence of anatomical variations of the VA at the C0-C1-C2 complex in patients with congenital skeletal anomalies of the craniovertebral junction (CVJ).

Objectives: To correlate specific bony craniovertebral junction anomalies with the VA course

Inclusion criteria: Patients with congenital bony craniovertebral junction anomalies with complete CT angiography studies done here in CMC Vellore

Exclusion criteria: Patients who underwent previous surgery at craniovertebral junction

Materials and methods

Patient population: We reviewed 86 patients with bony craniovertebral junction anomalies who underwent computed tomography angiography of CVJ at our institution from March 2005 to Apr 2012. Analysis of images done before 2007 was retrospective and those after 2007 was prospective. The population included sixty four males and twenty two females. Twenty patients were of paediatric age group (less than 18 years). Their mean age was thirty one years (range 6 years – 74 years; SD 15.5). They presented either with neck pain or restricted neck movements, myelopathy or myeloradiculopathy.

Computed tomography angiography: We performed three dimensional CT angiography (3D-CTA) in all eighty six patients prior to surgery and evaluated the VA anomalies. We used a light speed helical 6 slice CT scanner (Philips brilliance) with 0.5 sec/rotation. We used a nonionic contrast iohexol (OMNIPAQUE) for all patients.

Patients received 120 ml (2ml/kg) through a 20 gauge ante cubital vein catheter at a rate of 4 ml/sec. The CT angiography protocol involved a 90 kv peak, 250 mA, 300mm field of view, 512x512 matrix, 0.9 reconstruction pitch, 6x1.5 mm section collimation with slice thickness of 2 mm with 1 mm increment and the delay time of 5 sec. All images were reconstructed at 3 mm interval and transferred to work station (GEPACS) and all images were acquired with single acquisition.

The images were studied by the author, a radiologist and a senior neurosurgeon.   We studied the axial, coronal and sagittal views on the computed tomographic images of all 86 patients and described the VA course at C0-C1 complex. We identified the bony anomalies at the CVJ for each patient and then traced the course of VA on both sides at the C2-C1-C0 complex. We entered the details of right and left VA separately. The distance from the outer surface of the C1 lateral mass to the inner margin of the VA at the C1 level was measured. The collected data was entered into a Microsoft access database. We used the Pearson Chi-square test for statistical analysis.

Results

Of the 86 patients, 41 had an occipitalized atlas of which 39 were associated with basilar invagination (BI) and 2 were associated with atlantoaxial dislocation (AAD). Forty five patients had no occipitalization of the atlas. In these forty five cases, os odontoideum was present in 33 patients, atlantoaxial dislocation in 9 and basilar invagination in 3 patients.

There were 30 patients with complete bilateral occipitalization of the atlas and 11 in whom the atlas was partially occipitalised. The distribution of the partially occipitalised atlases were as follows: two patients had complete occipitalization on the left side and partial occipitalization on the right side. One patient had bilateral posterior arch occipitalization of atlas with the lateral masses and anterior arch separate from the occiput. Five patients had complete occipitalization only on right side with normal left sided C1 arch and one patient had occipitalization only on left side. One patient had right posterior arch and right lateral mass occipitalization and finally one patient with only the left anterior arch occipitalized.

We described the VA course on each side correlating it to the presence or absence of occipitalization, complete or incomplete, of the atlas. This is depicted in Table 3.

Three major types of abnormal courses of VA were identified.

Type 1. Artery enters dura below C1

a. Foramen transversarium present

b. Foramen transversarium absent

Type 2. Artery enters cranium through a canal in C0-C1 fused complex

a. Canal anterior to lateral mass

b. Canal posterior to lateral mass

i. Complete canal

ii. Incomplete canal

c. Canal within lateral mass

Type 3. Artery enters dura above C1 arch but foramen transversarium of C1 absent

Type 4. Normal VA course

It can be seen that in the 86 patients, 74 vertebral arteries (43%) were associated with occipitalization of atlas on the ipsilateral side while in the remaining 98 arteries (57%) the atlas was not occipitalized but there were other associated bony anomalies that will be described later.

	Occipitalization of atlas (74)				Non Occipitalized Atlas (98)		
	Complete Occipitalization (68)	Anterior arch occipitalization (1)	Posterior arch occipitalization (5)	Lateral mass occipitalization (0)	Basilar Invagination (12)	AAD (20)	Os Odontoideum (66)
Artery passing below C1 posterior arch entering dura in the presence of transverse foramen (type 1a) (9)	4	0	0	0	2	0	3
Artery passing below C1 posterior arch entering dura in the absence of transverse foramen (type 1b) (14)	11	0	0	0	1	1	1
Artery entering cranium through canal anterior to lateral mass (type 2a) (9)	8	1	0	0	0	0	0
Artery entering cranium through canal posterior to lateral mass: Complete (type 2b1) (26)	22	0	4	0	0	0	0
Artery entering cranium through canal posterior to lateral mass: Incomplete (type 2b2) (4)	4	0	0	0	0	0	0
Artery entering cranium through a canal within the lateral mass (type 2c) (20)	18	0	1	0	1	0	0
Artery passing above the C1 posterior arch in the absence of transverse foramen (type 3) (4)	0	0	0	0	3	0	1
Normal artery (type 4) (83)	0	0	0	0	5	19	59
Absent VA (3)	1	0	0	0	0	0	2

Table 3 Correlation of various VA anomalies with bony abnormalities

Occipitalization of atlas and VA course

The commonest course exhibited by the VA when the atlas was occipitalized was that it passed through a bony canal within the C0-C1 fused complex (Type 2) - 58 arteries (78.4%) were of this type (Figure 2). We further subdivided this group into three Types - 2a, b and c indicating that the canal was anterior, posterior or through the lateral mass respectively. Nine arteries (12.1%) coursed anterior to the lateral mass (Type 2a, Figure 12); 30 (40.5%) arteries entered the cranium through a canal posterior to the lateral mass (Type 2b) and 19 (25.6%) arteries coursed through a canal through the lateral mass (Type 2c, Figure 15). In Type 2b we found that the canal was complete in 26 (35.13%) arteries while the canal was incomplete in 4 (5.4%) arteries.

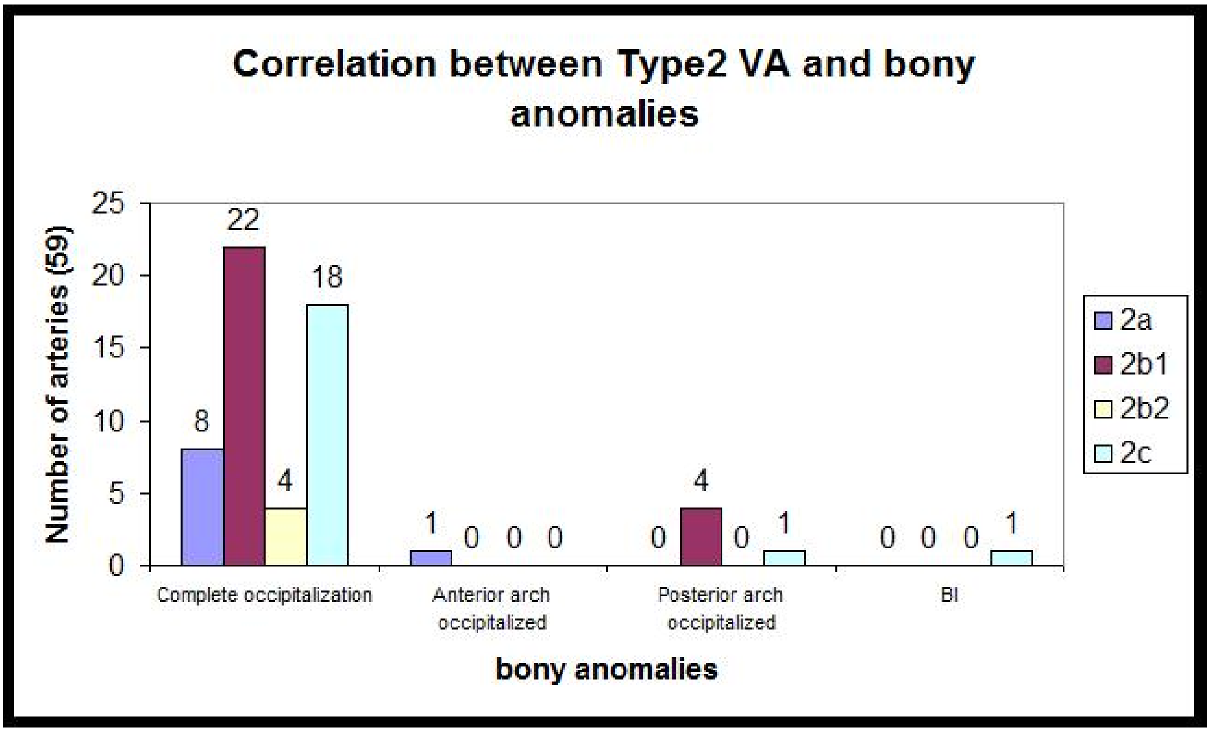


Fig 2. Correlation between type 2 VA and bony anomalies

The next most common course of the VA in occipitalization of the atlas was Type 1, in which the VA passed under the C1 posterior arch and entered the dura below the C1 arch (Figure 3). There were 15 (20.3%) such arteries that exhibited this course – 9 on the right and 6 on the left side. We further classified them into two groups depending on the presence or absence of an ipsilateral C1 transverse foramen. In 4 arteries the transverse foramen was present but not traversed by the artery (Type 1a) and in 11 the C1 transverse foramen was absent (Type 1b, Figure 15).

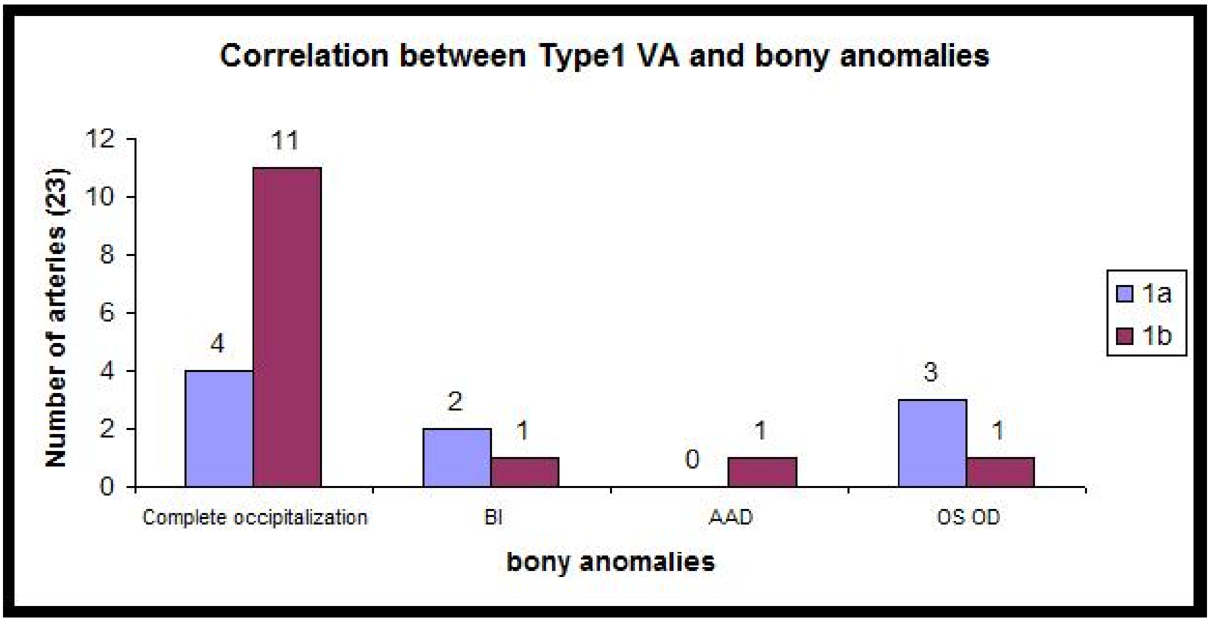


Fig 3. Correlation between type 1 VA and bony anomalies

Type 3 and Type 4 vertebral artery was not seen in any case with occipitalization, however in one patient the vertebral artery was absent on the left side in which the atlas was completely occipitalized.

To summarize, all 74 arteries (100%) had an abnormal course when occipitalization of atlas was present (Figure 4); fifteen (20.3%) were Type 1 (passing below the C1 posterior arch) and 58 (78.4%) were Type 2 (passing through a canal formed in the C0-C1 fused complex). In one patient the artery was absent at C0-C1 on the left side.

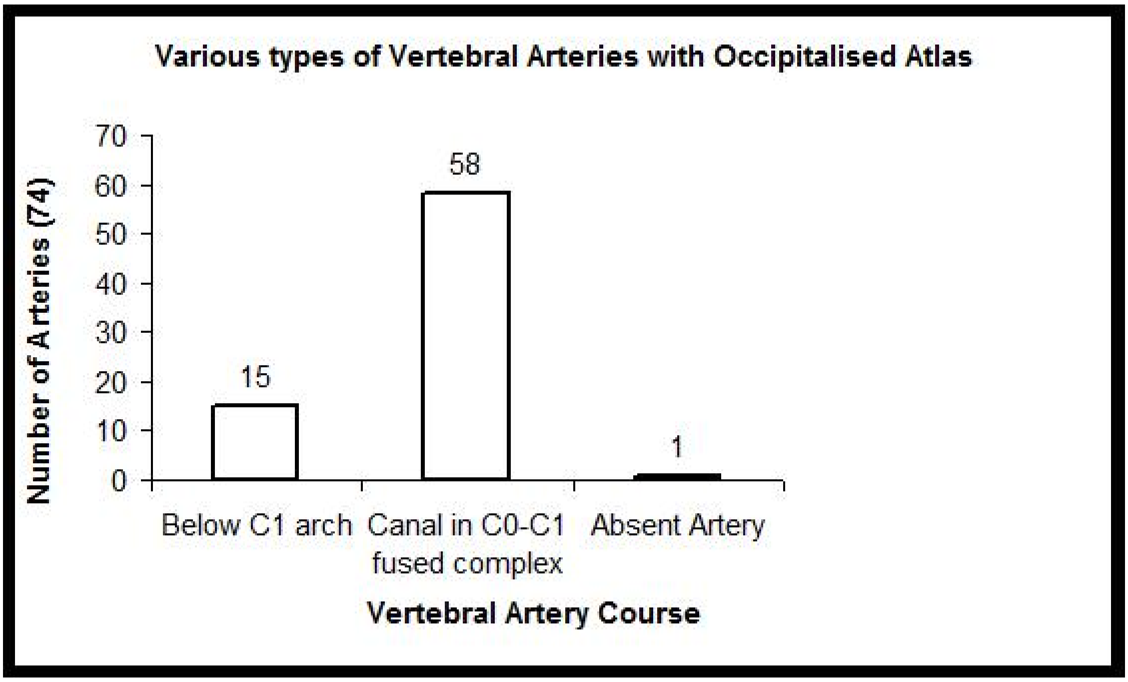


Fig 4. Various types of vertebral arteries with occipitalised atlas

VA course in a non-occipitalized atlas:

The various types of VA courses noted in patients with a non-occipitalized atlas are shown in Table 3. Of the 98 arteries, the majority, 83 (84.7%) arteries had a normal course, (Type 4), that is, those that passed through the C1 transverse foramen, above the C1 posterior arch and then entered the dura (Figure 5). Fifty nine arteries (71.2%) were associated with os odontoideum, nineteen (22.9%) with atlantoaxial dislocation and five (6%) with basilar invagination. Only 15 arteries (15. 3%) showed an abnormal course. Compared to the VA course in occipitalized atlases the p value obtained by using Pearson Chi-square test was <0.001.

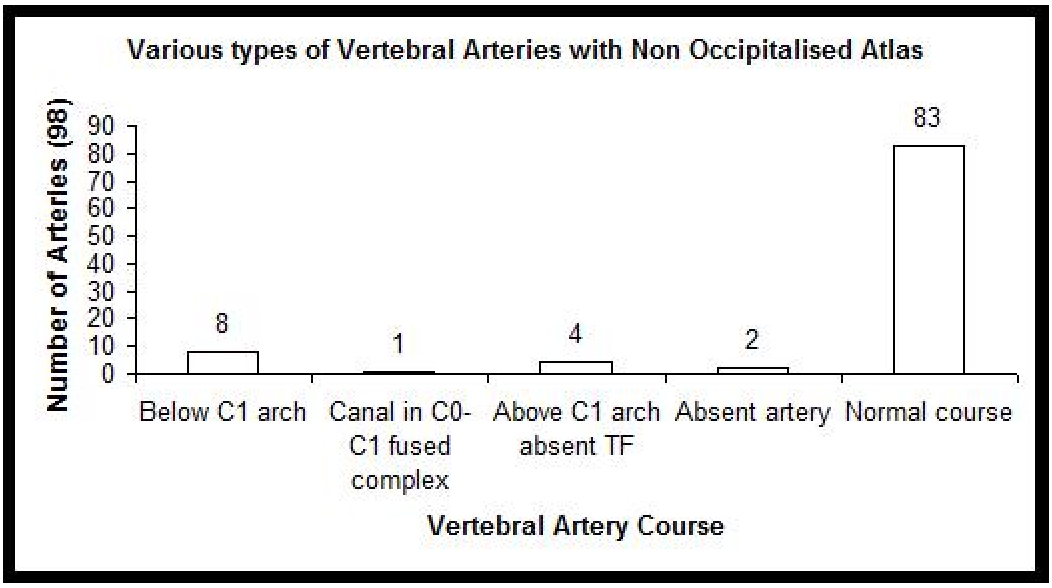


Fig 5. Various types of vertebral arteries with non-occipitalized atlas

Of the 15 abnormal arteries, 8 were of Type 1 (passing below the C1 posterior arch), five of which did not enter the C1 transverse foramen (Type 1a, Figure 10) while the C1 transverse foramen was absent in three (Type 1b, Figure 11). One artery exhibited a Type 2c course, that is, it passed through a canal within the lateral mass of C1 although the lateral mass could be seen separate from the occipital (Figure 6).

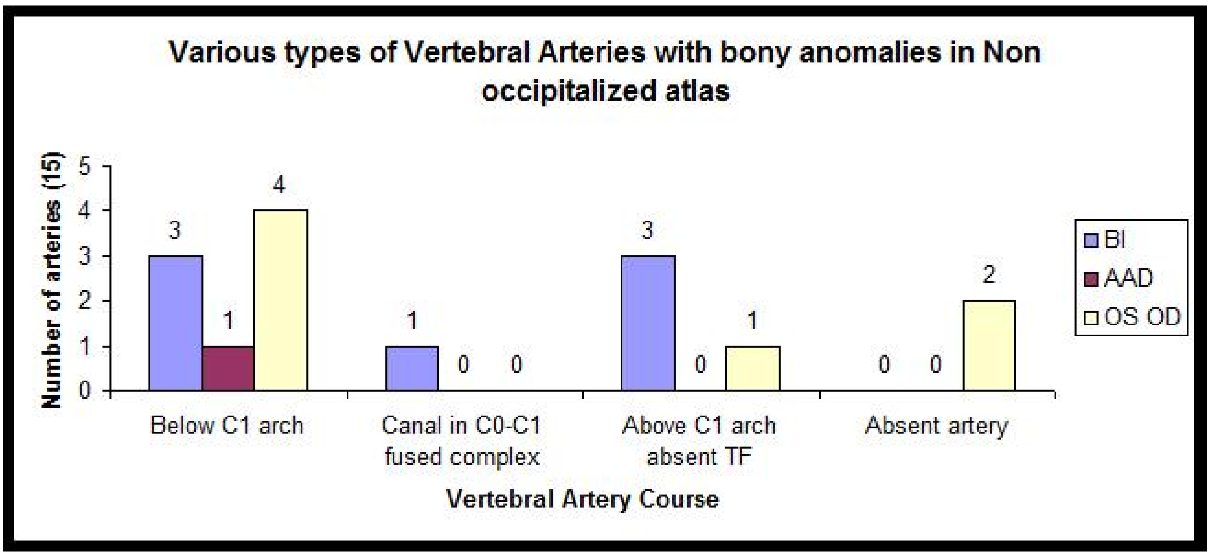


Fig 6. Various types of vertebral arteries with bony anomalies in non-occipitalized atlas

The arteries that passed above the C1 posterior arch in the absence of an ipsilateral C1 transverse foramen were grouped as Type 3 (Figure 7, 16). There were 4 arteries in this group, 3 were associated with basilar invagination and 1 with os odontoideum.

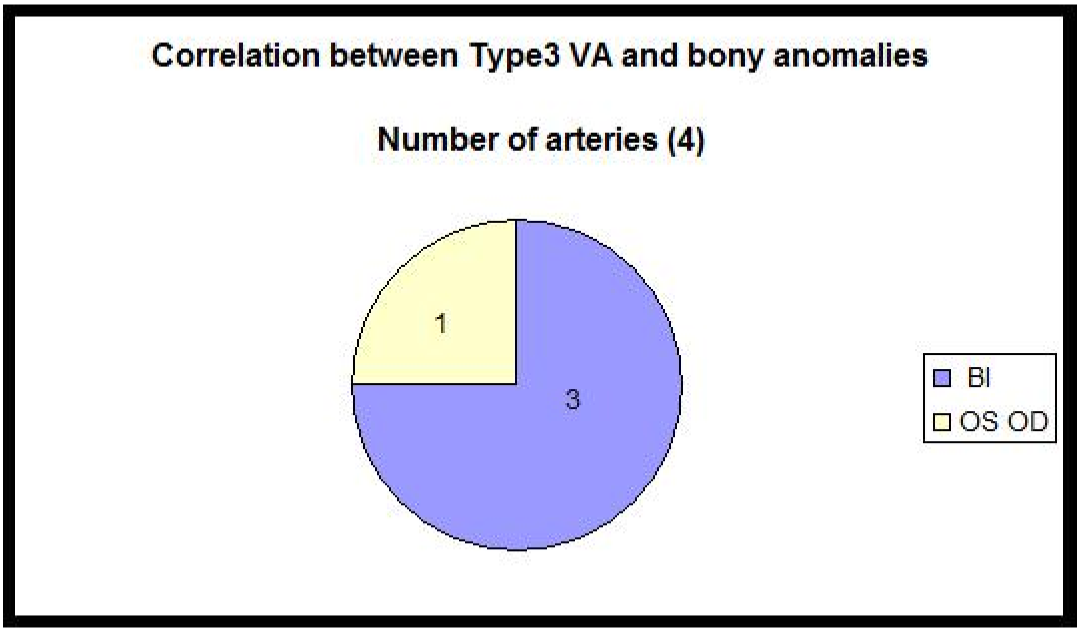


Fig 7. Correlation between type 3 VA and bony anomalies

Apart from the above mentioned anomalies two arteries were atretic or absent unilaterally in association with os odontoideum (Figure 8).

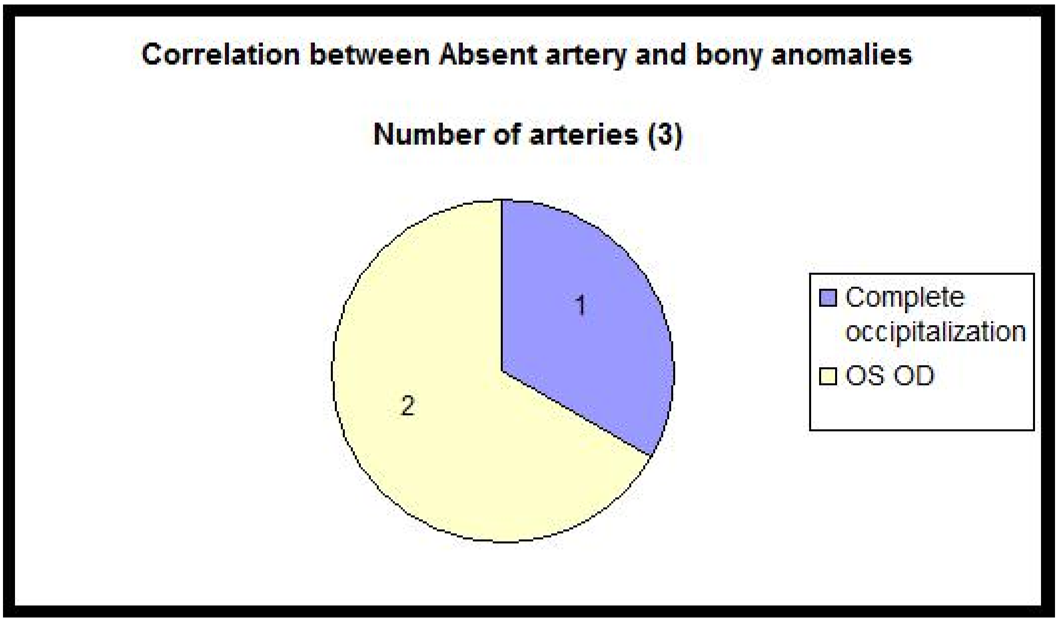


Fig 8. Correlation between absent artery and bony anomalies

In summary, of the 98 arteries in association with a normal atlas separate from the occiput, 83 (84.7%) had a normal course and only 15 arteries (15. 3%) showed an abnormal course (Figure 9). Of the 66 vertebral arteries with os odontoideum 59 (89.4%) were normal. In 20 arteries with atlantoaxial dislocation 19 (95%) were normal. 12 arteries were associated with basilar invagination with non-occipitalized ipsilateral atlas, of which 5 (41.7%) were normal.

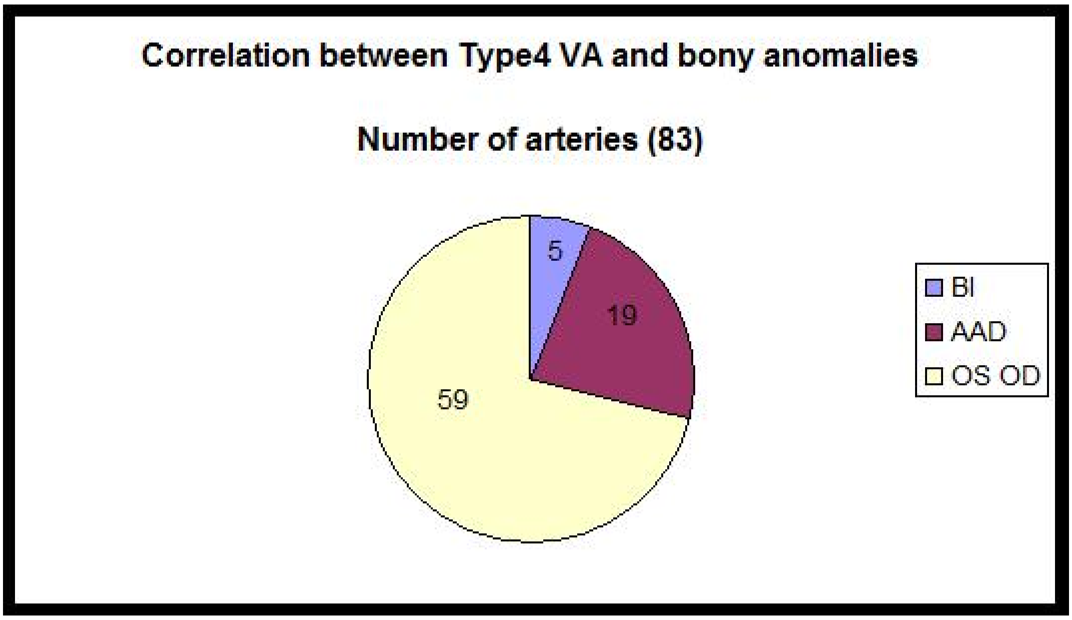


Fig 9. Correlation between type 4 VA and bony anomalies

Redundant loop (posterolateral protrusion of VA at C1 lateral mass): Ninety two vertebral arteries had a redundant loop situated at a distance from the C1 lateral mass (Fig 17). Fifty one arteries on the right side had this loop and forty one arteries on the left side had this loop. In 36 cases it was present bilaterally. Of these 92 arteries, 20 (21.7%) were associated with occipitalized atlas and 72 (78.3%) with non-occipitalized atlas. In the non-occipitalized atlas, 55 (76.4%) arteries were associated with os odontoideum, 11 with atlantoaxial dislocation and 6 with basilar invagination. The redundant loop seems to be mainly in those with os odontoideum and AAD. On the right side the loop's diameter range was (2mm - 12mm) mean 6 mm and SD 2.6 mm. On the left side it was (2mm – 11mm) with mean of 5.5

mm and SD of 2.4mm. There is no significant difference in the mean diameter in the occipitalized group, in os odontoideum and in other bony anomalies (AAD and BI).

Diameter of the VA: The mean diameter of the artery at the level of C1 lateral mass, on the right side was 3.7 mm and standard deviation of 1.125 with range of (1mm-8mm) and mean on the left side was 3.6mm and standard deviation of 1.114 with range of (1-8mm). 28 arteries (32.55%) were dominant on the right side, 30 arteries (34.88%) were dominant on the left side and 26 arteries (30.28%) were equal on both side

Discussion

For craniovertebral junction anomalies, several methods of occipitocervical and C1-C2 fixations have been described including C1-C2 transarticular screw fixation, C1-C2 lateral mass fixation and occipito cervical fixation. These procedures essentially require exposure of the C1-C2 facet joints and foramen magnum. Various authors [33, 54] have cautioned against injury to the artery particularly on the dominant side, during the exposure of this region and subsequent screw placement that may have a devastating outcome. There have been various reports[54] of VA injury as a complication of the C1–C2 transarticular screw fixation, including arteriovenous plexus fistula, occlusion, narrowing or dissection of the VA which could lead to transient ischemic attacks, brain stem and cerebellar infarct or death. A large survey[54] on 2,492 C1–C2 transarticular screw placements in 1,318 patients reported a 4.1% risk of VA injury per patient, 0.2% risk of subsequent neurological deficit and a mortality rate of 0.1% per patient (1.9% per VA injury case).

Variations in VA anatomy at the C2 level are reported unilaterally in 3% and bilaterally in 18% of patients where transarticular screw placement cannot be done.[33]In these cases, alternate procedures like C1 lateral mass-C2 pedicle and C2 pars screw instrumentation may be considered.

Prior to 3D-CTA, a non-invasive method of determining the course of the VA, in bony craniovertebral junction anomalies was not available. The 3D-CTA shows excellent bony anatomy in addition to precise delineation of the VA course that is invaluable preoperative information for the operating surgeon.

Occipitalization of atlas, also known as assimilation of atlas, results from the complete or partial failure of segmentation of the fourth occipital sclerotome from the first spinal sclerotome. Partial occipitalization may be present either in the anterior arch or posterior arch or may be limited to the lateral mass alone. Furthermore, the occipitalization may be unilateral with a completely normal arch on the other side. Since the VA typically enters the cranium posteriorly above the C1 arch, occipitalization of lateral mass or posterior arch of the atlas may affect the course of the VA that should take an alternate route to enter the cranium. Since occipitalization of the atlas is a fairly common congenital defect, that may be associated with other craniovertebral junction anomalies requiring surgery, we did this study to document the course of the VA in such cases and reduce the risk of intraoperative VA injury.[52]

Congenital craniovertebral junction anomalies

In this series of 86 patients the distribution of bony CVJ anomalies were as follows. Thirty eight patients (44.2%) had basilar invagination, 34 (39.6%) had os odontoideum and 14 (16.3%) had atlantoaxial dislocation. Of these, 41 had occipitalization of atlas and in 45 the atlas was not occipitalized. The incidence of assimilation of atlas reported in general population is 0.25%[24] and basilar invagination was 1%.[56]

Previous authors [39] have described (Table 2) 4 types of VA courses in cases of occipitalized atlas after reviewing 72 arteries using 3D-CTA. The commonest course seen in 61% of cases was that which the artery passed through the transverse foramen of the atlas and entered an osseous foramen created between the fused atlas and occiput. But these authors did not comment on the location of the VA in relation to the fused C0-C1 complex. In the remaining cases the artery passed below the C1 arch or was absent on that side. In five cadaveric specimens with occipitalization of atlas, Tubbs et al[48] also showed that the intracranial entrance of the VA in occipitalization of the atlas was through an osseous foramen created between the fused atlas and occipital bone.

VA course in occipitalization of atlas

We modified the Shenglin Wang et al[39] classification to include a detailed study of the topographical relationship of the VA to the lateral mass. In cases of occipitalized atlas where the VA passes through a canal, we documented the relationship of the bony canal to the lateral mass of C1 in the C0-C1 fused complex as this is considered to be an important bony landmark in many stabilization procedures at the C0-C1-C2 complex. In cases where the VA passed below the C1 arch we also noted whether the VA passed through the C1 transverse foramen.

We studied 172 vertebral arteries, of which 3 were atretic or absent. Occipitalization of the atlas was seen in 41 patients, unilateral in 11 and bilateral in 30. On considering the VA on each side, 74 (43%) arteries were associated with occipitalization of atlas on that side. All 74 arteries (100%) had an abnormal course with 58 (79.5%) entering the cranium through a canal within the C0-C1 fused complex and 15 (20.3%) passing below the posterior arch of atlas. The bony canal was situated posterior to the lateral mass in the majority of cases (40.5%), was through the lateral mass in 19 arteries (25.6%) and anterior to the lateral mass in 9 arteries (12.1%). Of the 15 vertebral arteries (20.3%) that passed below the C1 posterior arch, 11 had no transverse foramen in C1 while four had a transverse foramen that was not traversed by the VA. This anomaly is called a persistent first intersegmental VA (C2 segmental type of the VA) .[49] In this anomaly the VA exits the transverse foramen of C2, courses under the posterior arch of the atlas and enters the dura below C1 instead of following its normal path through the C1 transverse foramen and then entering the dura between C1 and C2. Our results show that the VA can display different courses on each side in the same patient and was seen in 24 cases. This is primarily because the C1 posterior arch may be partially occipitalised on one side and completely occipitalised on the other – this situation was seen in 9 cases. The VA may pass through a canal in the C0-C1 complex on one side but may pass below the C1 posterior arch on the opposite side. It is important to do a 3D-CTA in these patients with bony craniovertebral junction anomalies to make a meticulous preoperative plan regarding various fusion methods particularly in cases of occipitalization of atlas where there is 100% occurrence of anomalous artery. We need to see whether the artery passing below the C1 arch or passing through a canal in C0-C1 fused complex and also the status of transverse foramen. It is also important to see the dominance of the VA as injury to dominant VA during any surgical procedure may lead to severe untoward complications as the vascular supply from the other side of the VA may be negligible or absent.

VA in non-occipitalized atlas

In contrast, in cases of non-occipitalized atlas, the majority of the arteries were normal. Among 98 vertebral arteries 83 (84.7%) were normal and only 15 (15.3%) vertebral arteries had an abnormal course. Of these, 8 vertebral arteries passed below the C1 posterior arch amongst which 5 arteries (3 with os odontoideum and 2 arteries with basilar invagination) did not traverse the ipsilateral C1 transverse foramen while three passed below the C1 posterior arch in the absence of ipsilateral transverse foramen. Four arteries traversed above the C1 posterior arch in the absence of ipsilateral C1 transverse foramen making the VA more prone for injury. Of 98 vertebral arteries with non-occipitalized atlas, 83 arteries had normal course which passed through C1 transverse foramen, above the C1 posterior arch and entered the dura.

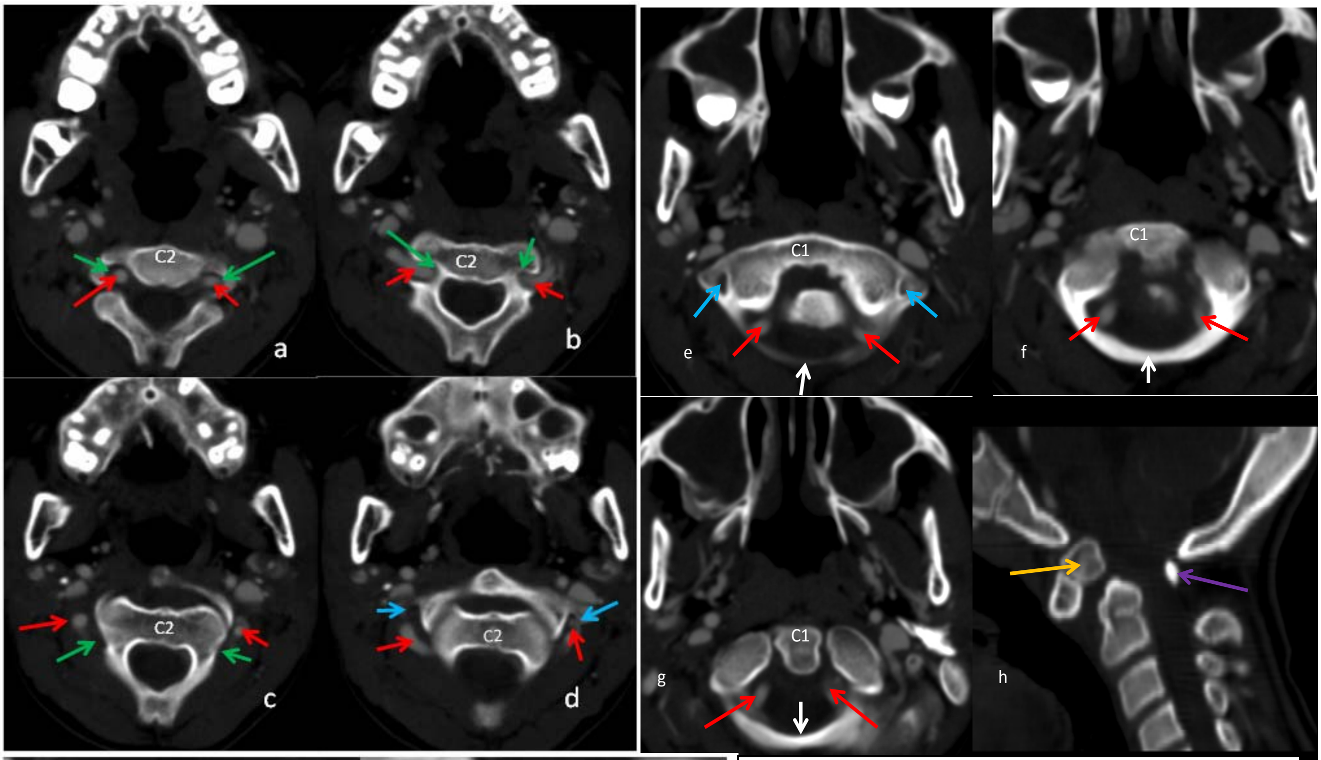
Redundant VA loop

Satoshi et al[37] observed in 133 patients with 3D-CTA that the VA made a loop after exiting from the C1 transverse foramen. The artery coursed posterolaterally and then made an anteromedial turn to cross over the superior surface of the C1 posterior arch. These changes in direction produced a posterolateral protrusion of the VA. The same authors also measured the maximum length of the perpendicular line drawn from the outer surface of the vertebral artery to the outer surface of the posterior arch of the atlas. They found that on the right side this distance ranged from 1.39 mm to 14.10 mm with a mean of 6.73 and on the left side, the range was 1.44 mm to 13.65 mm and the mean was 6.8. We measured the distance from the outer surface of the C1 lateral mass to the inner edge of the vertebral artery. In our series we considered a minimum distance of 2 mm as a loop. We observed this loop in 92 (53.5%) vertebral arteries. On the right side among the 51 loops, the loop's diameter range was (2mm - 12mm) with a mean of 6 mm and standard deviation of 2.6 mm. On the left side it was (2mm – 11mm) with a mean of 5.5 mm and standard deviation of 2.4 mm. There is no significant difference between the two sides and is similar to that described in the literature. In 36 cases it was present bilaterally. Among 92 arteries with loop, 57 had os odontoideum, 22 had basilar invagination and 13 had atlantoaxial dislocation as bony anomalies. In 48 patients with AAD and os odontoideum 43 patients had this loop and in remaining 38 patients, this arterial loop present only in 13 (23.2%) patients with a P value of <0.001. Only 20 arteries were associated with occipitalized atlas. So, this loop was seen more commonly in the cases of non occipitalized atlas rather than occipitalized atlas. This redundant loop is mostly seen in patients with os odontoideum and AAD because of the great degree of vertebral movement the artery has to be redundant or the patient will die with kinking of the artery. There is no significant difference in the mean diameter in the occipitalized group, in os odontoideum and in other bony anomalies (AAD and BI). So, in addition to anomalous course 3D-CTA is required to find the loop of the artery around the C1 lateral mass especially in non occipitalized group where it is more common.

Conclusions

Various anomalies in the VA course are described in patients with congenital craniovertebral junction anomalies. When the C1 was occipitalised, irrespective of other bony anomalies, the VA passed through a canal formed in the C0-C1 fused complex or it entered the dura below the C1 posterior arch in all cases. When the C1 was not occipitalised the VA course was abnormal in only 15% of cases either passing below the C1 posterior arch or not lying in the C1 transverse foramen. A redundant loop of the VA was noted mainly in those vertebral anomalies with excessive C1-C2 movement as in os odontoideum and atlantoaxial dislocation.

Images showing various vertebral artery anomalies



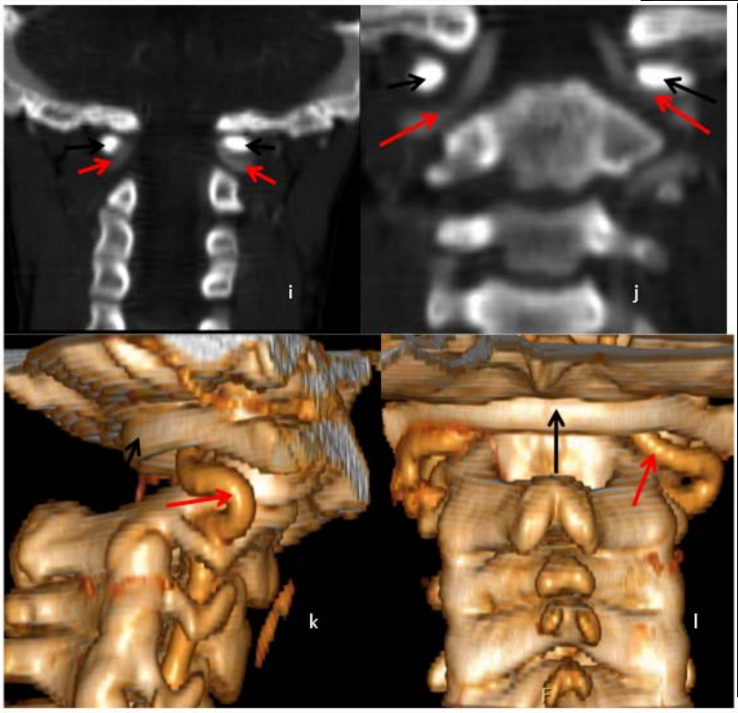
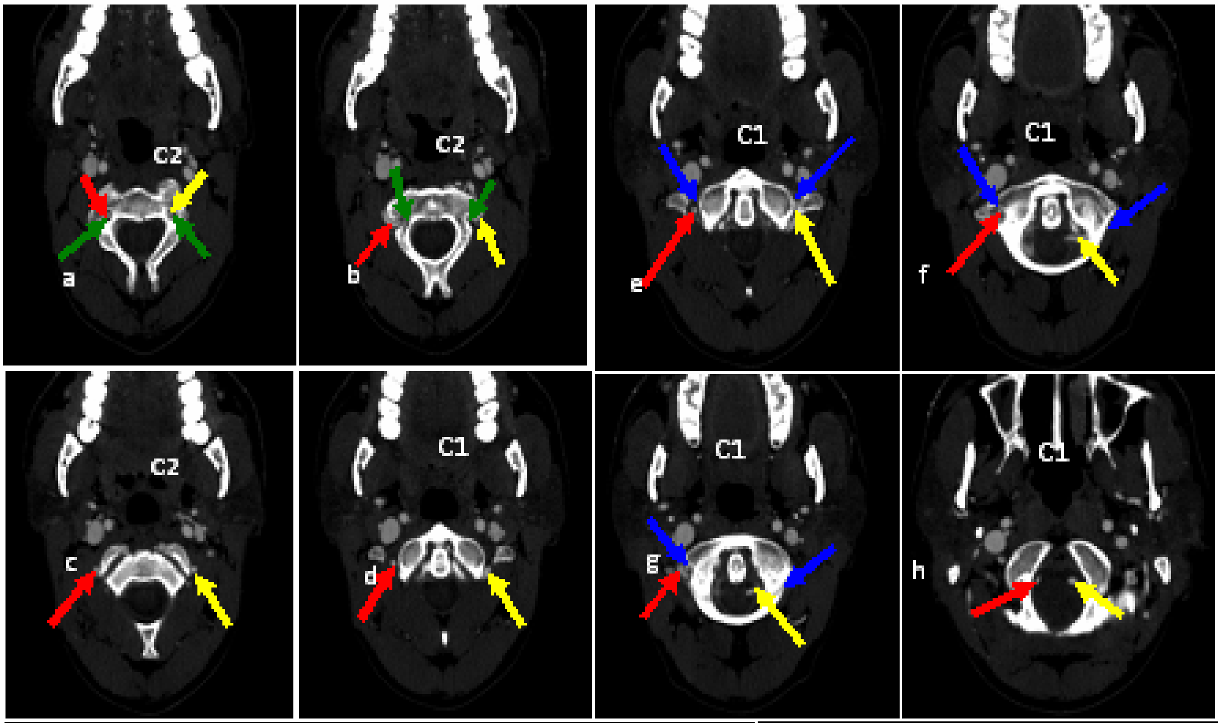


Figure 10: Vertebral artery entering the dura below the C1 posterior arch bilaterally – with unoccupied transverse foraminae (bilateral Type 1a vertebral arteries). a), (b), (c), (d) axial CT angio images of a patient with an os odontoideum. (a) both vertebral arteries (red arrows) are seen in the C2 transverse foraminae (green arrows); (b)they exit the C2 transverse foraminae (c&d) bypass the C1 transverse foraminae (blue arrows) (e,f,g) and enter the dura beneath the C1 arch (e,f,g). The sagittal image (h) shows the os odontoideum (orange arrow) with a non-occipitalized posterior arch of atlas (purple arrow). The coronal images (i,j,k,l) clearly show the vertebral arteries (red arrows) passing below the C1 posterior arch (black arrows)



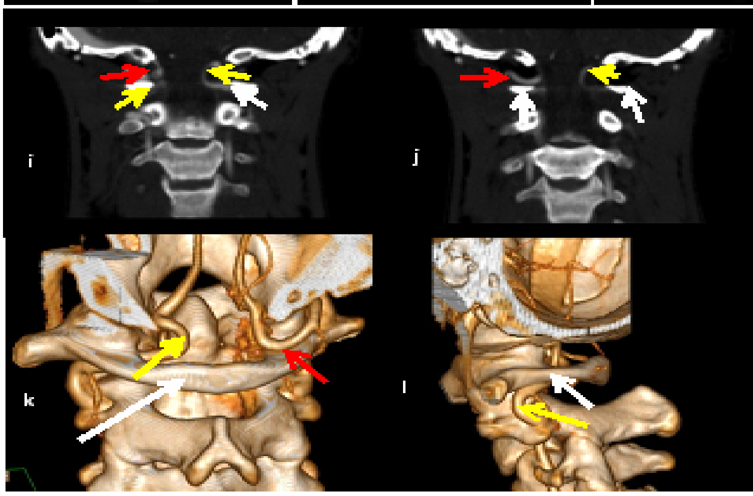
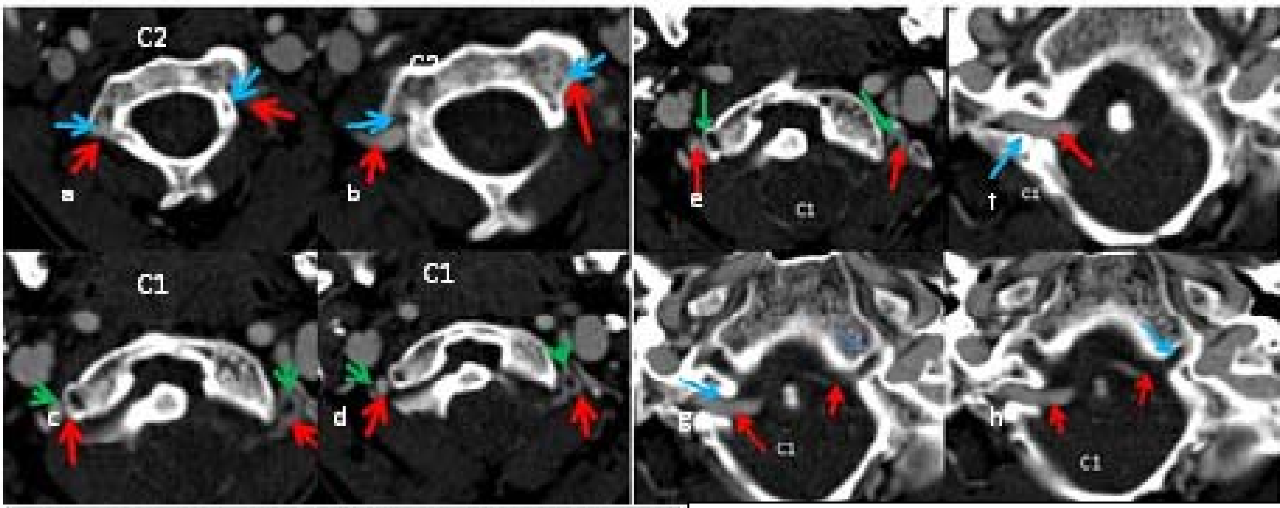


Figure 11: Left vertebral artery entering the dura below the C1 posterior arch - in the absence of an ipsilateral C1 transverse foramen (Type 1b). The right artery was normal (Type 4). (a),(b),(c) and, (d) axial CT images through C2 and C1 of a patient with an os odontoideum. (a) the vertebral arteries (yellow and red arrows) are within the C2 transverse foraminae (green arrows). (b),(c) and (d) the arteries exit the C2 transverse foraminae and course towards the C1 (e,f) C1 vertebra has no transverse foramen (blue arrow) on the left side while it is present on the right side (blue arrow). (f),(g),(h) the left vertebral artery (yellow arrow) passes below the C1 posterior arch and enters the dura, while the right vertebral artery (red arrow) has a normal course above the C1 posterior arch. (i),(j) coronal CT images (k), (l) reconstructed images show the above described course of the vertebral artery (yellow arrow) below the C1 posterior arch (white arrow) classifying as Type 1b on the left side and as Type 4 on the right side.



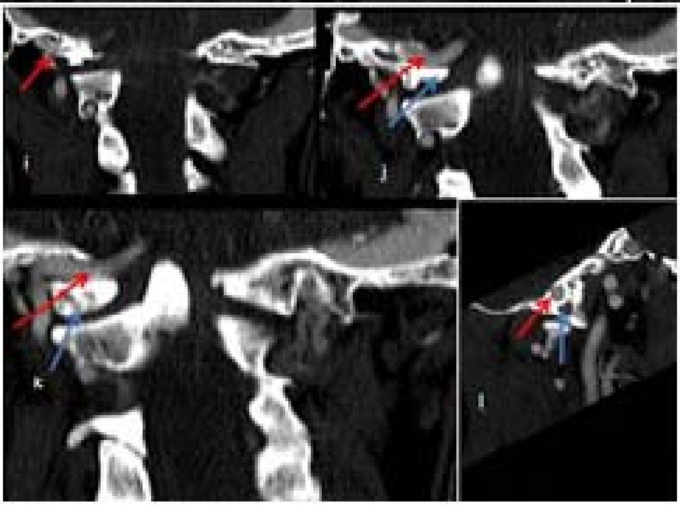


Figure 12: Vertebral artery entering the dura in the canal passing through a canal anterior to the C1 lateral mass in C0-C1 occipitalized complex on the left side and passing through a canal within the C1 lateral mass on the right side. (Left Type 2a and right Type 2c). (a), (b), (c), (d) axial CT images of a patient with basilar invagination and occipitalization of atlas. (a,b) the arteries (red arrows) exit from the C2 transverse foraminae (blue arrows). (c, d) the arteries course towards the C1 transverse foraminae (green arrows). (e), the arteries are seen in the C1 transverse foraminae (green arrows). (f),(g),(h) the right vertebral artery passes through the canal (blue arrow) within the lateral mass (white arrow) and the left artery passes through a canal (blue arrow) anterior to the C1 lateral mass (white arrow). (i),(j),(k),(l) the coronal images show the right vertebral artery passing through a canal within the C0-1 fused lateral mass (blue arrow).

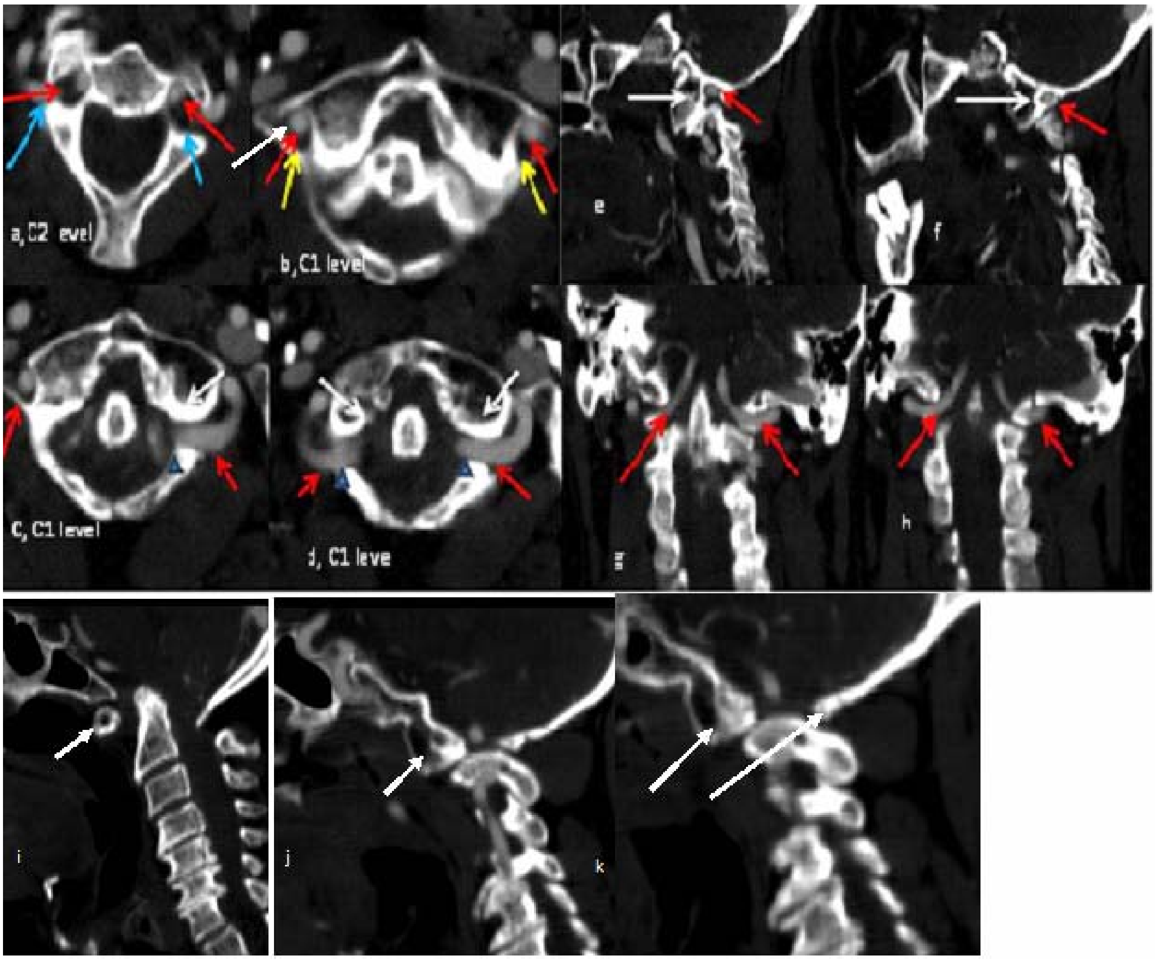


Figure 13: The vertebral artery passes through a complete canal situated posterior to the C0-C1 fused complex. (Bilateral 2b1)
(a), (b), (c), (d), axial images of a patient with basilar invagination and completely occipitalized atlas on the left side and only occipitalizied posterior arch on the right side showing the VA (red arrows) passing from C2 to C1 and then sweeping posteriorly into a canal posterior to the C1 lateral mass (white arrows). (e),(f),(g) and (h)the sagittal and coronal reconstructed images show the VA entering the cranium through a canal located in the fused C0-C1 complex posterior to the C1 lateral mass (white arrows). (i),(j),(k) sagittal images showed a free anterior arch on the right side and completely occipitalized atlas on the left.

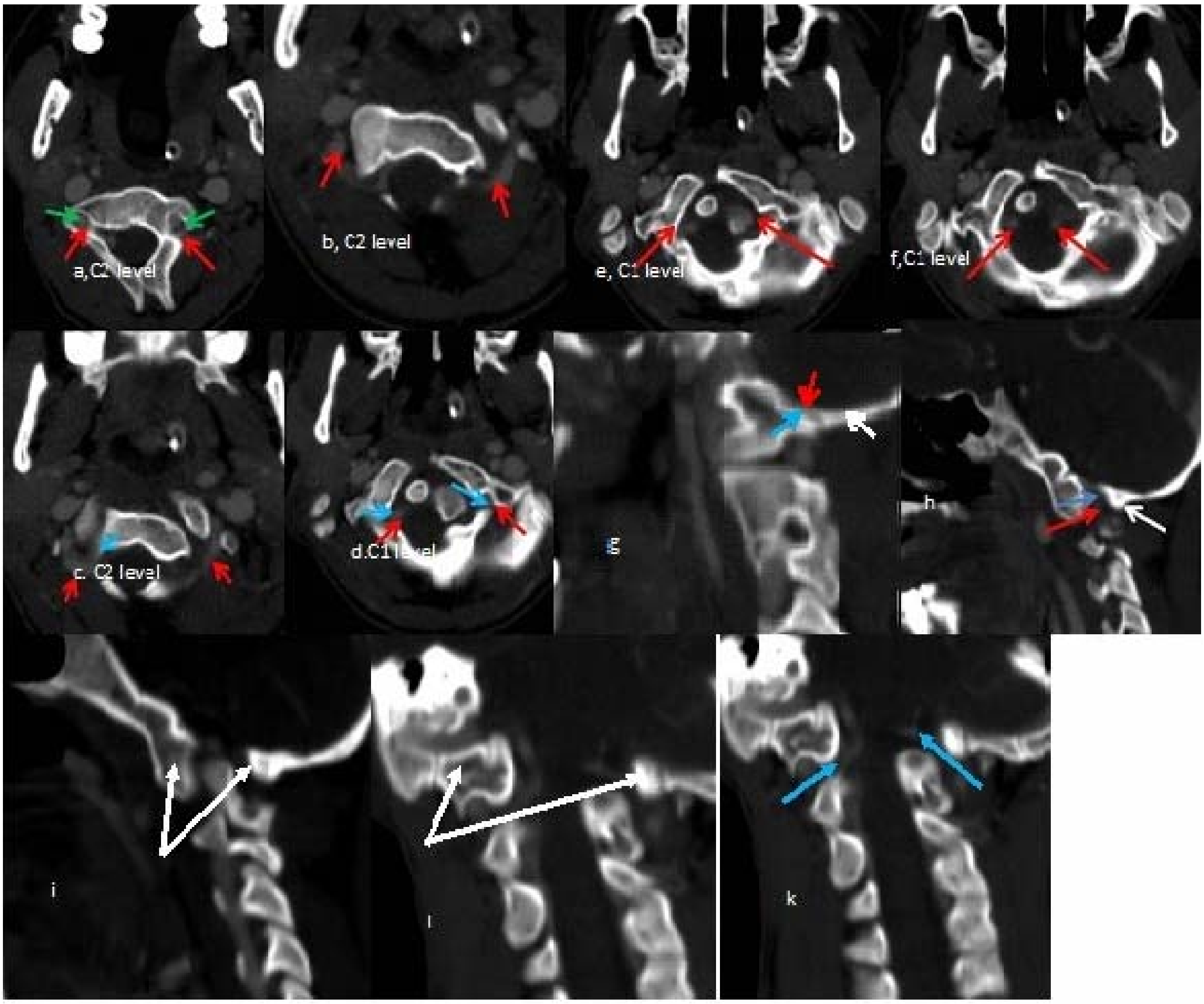


Figure 14*: *The vertebral artery passes through an incomplete canal situated posterior to the C0-C1 fused complex. (Bilateral 2b2).

(a), (b), (c), (d), (e), (f) axial images of a patient with basilar invagination and a completely occipitalized atlas. (a) both arteries (red arrows) are seen in the C2 transverse foraminae (green arrows), (b) cranial to the C2 transverse foraminae. (c and d) the VAs pass through an incomplete canal (blue arrow) in the C0-C1 fused complex, posterior to the C1 lateral mass. (e,f) both vertebral arteries (red arrow) are passing through an incomplete canal (g,h,i,j) sagittal images show completely occipitalized atlas (white arrows) and the canal (blue arrow) is seen posterior to C1 lateral mass. Coronal view (k) showed the arteries passing through a canal. Vertebral arteries are classified as Type 2b2

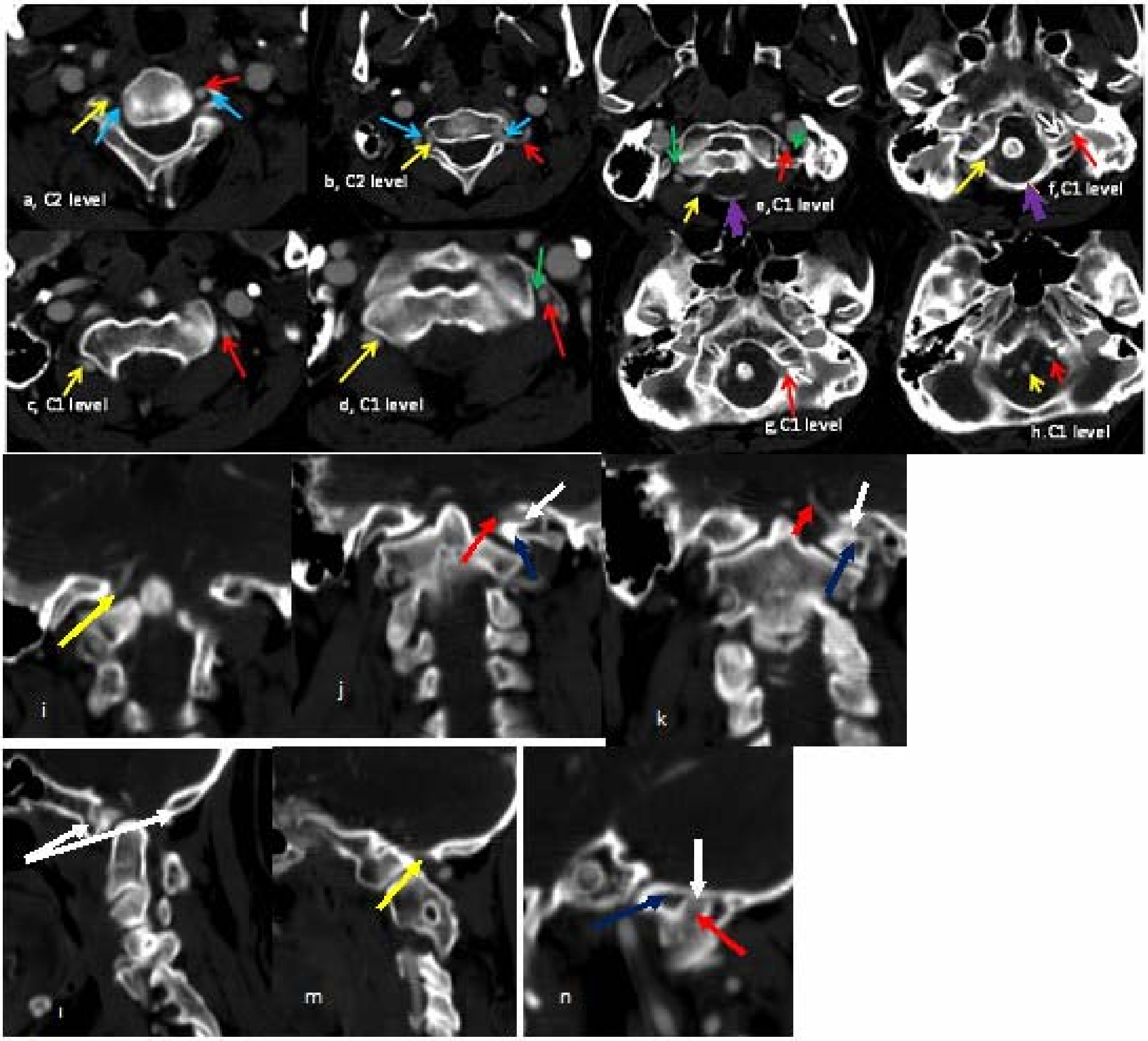
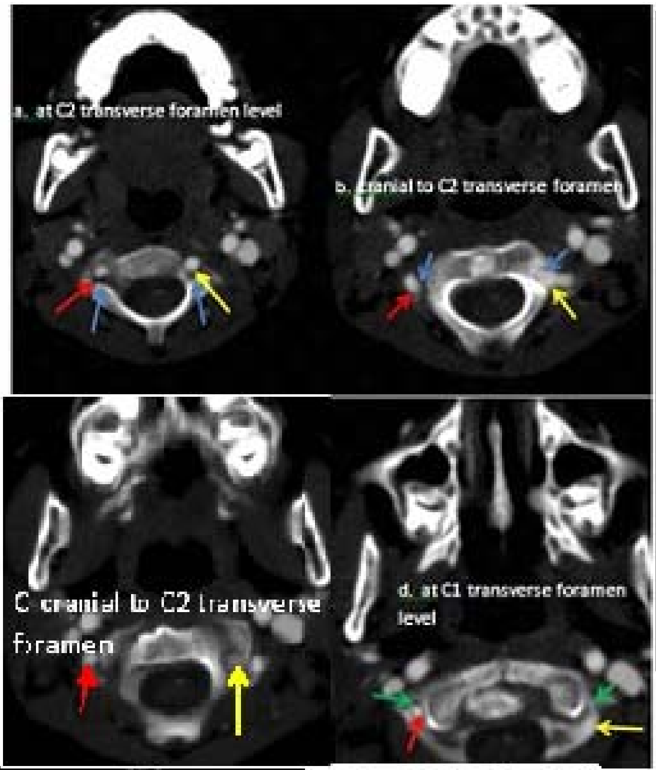


Figure 15: The right vertebral artery passesbelow the C1 posterior arch in the absence of ipsilateral C1 transverse foramen and the left vertebral artery passes through a canal within the C1 lateral mass. (Right Type 1b and left Type 2c). (a),(b),(c),(d) axial images of a case of basilar invagination and complete occipitalization of atlas. (a) both vertebral arteries (yellow and red arrows) are seen within the C2 transverse foraminae (blue arrows), (b) both arteries exit from the C2 transverse foraminae (blue arrows) and pass cranially from the C2 transverse foraminae towards the C1 transverse foramen (green arrow).(c,d,e) the arteries (yellow and red arrows) seen in the C1 transverse foraminae (green arrow).(f and g) showing the right vertebral artery (yellow arrow) is passing below the C1 posterior arch (purple arrow) and the left vertebral artery is passing through a canal (white arrow) within the C1 lateral mass. (h) both vertebral arteries are seen within the spinal canal. (i) right vertebral artery passing below the occipitalized C1 arch. (j,k) left vertebral artery passing through a canal (white arrow) in the C1 lateral mass (deep blue arrow). (l) basilar invagination with complete occipitalization (m) right artery (yellow arrow) passing below the C1 arch (n) the left artery (red arrow) is seen in the canal (white arrow) within the C1 lateral mass (deep blue) of C0-C1 complex.



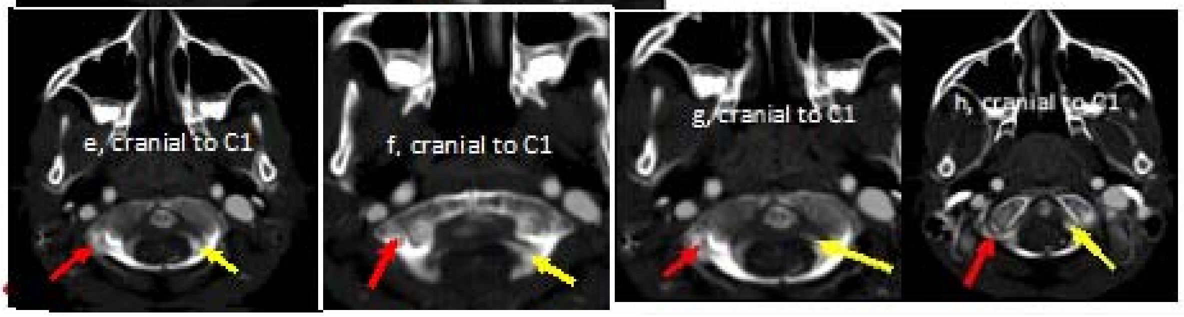


Figure 16: ***The left VA had a normal course above the C1 posterior arch in the absence of an ipsilateral transverse foramen. The right VA had a normal course after exiting from the ipsilateral transverse foramen. (Left Type 3 and right Type 4)*** (a),(b),(c),(d), CT axial images of a case of os odontoideum with a non-occipitalized atlas. (a) both the vertebral arteries (red and yellow arrows) are seen in the C2 transverse foraminae (blue arrow). (b,c) the arteries are exiting the C2 transverse foramine and coursing towards the C1 transverse foraminae. (d) the right vertebral artery (red arrow) is seen within the C1 right transverse foramen (green arrow) but there is no transverse foramen (green arrow) on the left side. (e),(f),(g),(h) both are passing above the C1 posterior arch.

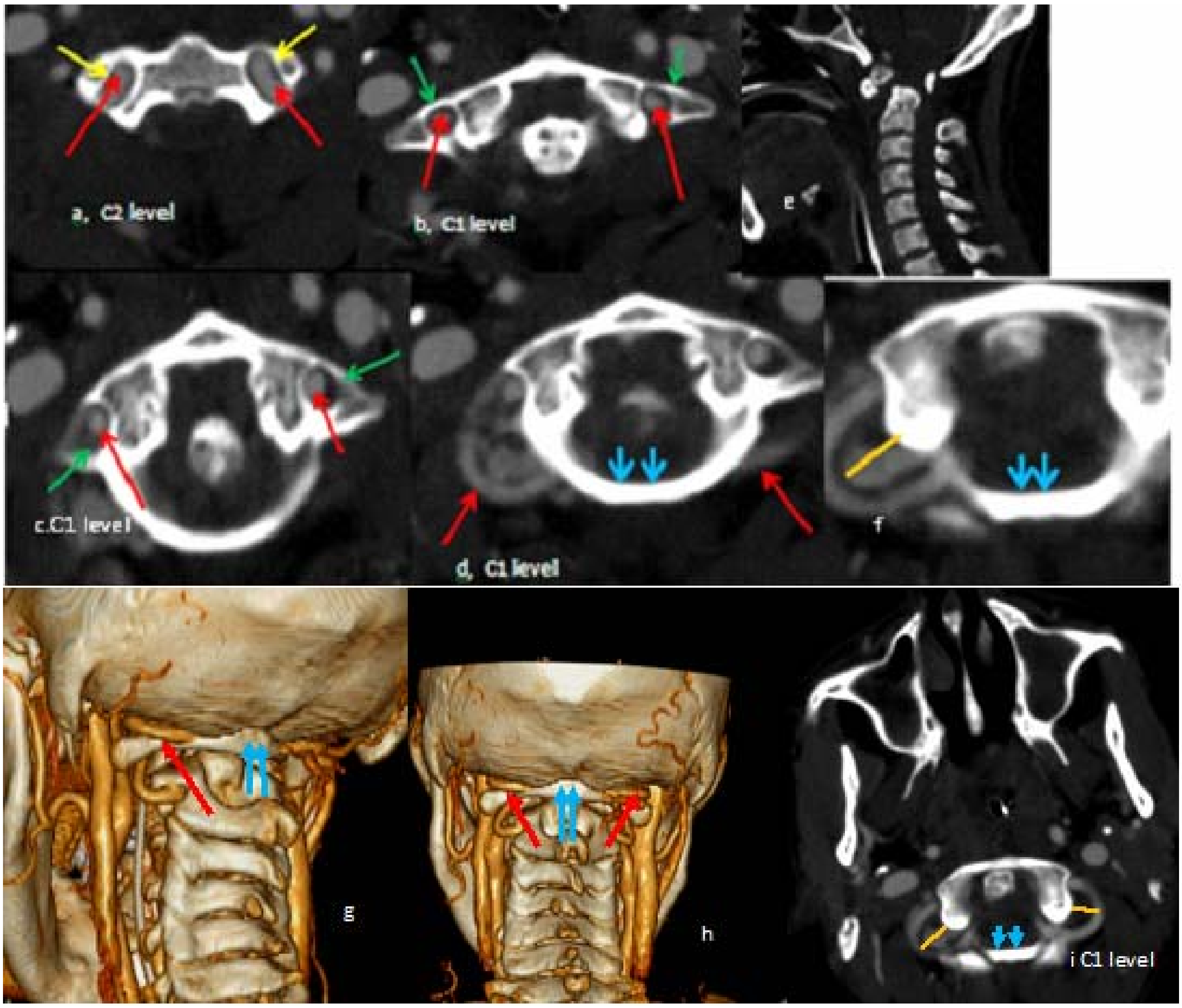


Figure 17: Both the vertebral arteries pass above the C1 posterior arch after exiting from the ipsilateral C1 transverse foraminae and forming a loop at the C1 lateral mass (Bilateral Type 4 vertebral arteries with a redundant loop on either side). (a),(b),(c),(d) axial images of a case of os odontoideum with a non occipitalized atlas. (a) The vertebral arteries (red arrows) are seen in the transverse foraminae of C2 (yellow arrows). (b,c) the vertebral arteries are seen within the C1 transverse foraminae level (green arrows). (d) both arteries course above the C1 posterior arch (double blue arrows) and enter the dura. (e) sagittal image shows the os odontoideum. (f) At the level of C1 lateral mass there is a redundant loop (orange line). (g,h) reconstructed images showed the arteries making loop around the C1 lateral mass. (i) The loop is seen bilaterally.The distance of the loop from the lateral mass measured 8 mm on the right side and 6 mm on the left side. .This is normal course and classified as Type 4.

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Addendum -1

CT ANGIO STUDY OF VA COURSE IN CVJ PATHOLOGY

PROFORMA

NAME

H.NO

AGE

SEX

	I. OBSERVER	II. OBSERVER
CRANIOMETRIC VALUES		
CHAMBERLEIN'S LINE		
MC RAE'S LINE:		
WELCHER'S BASAL ANGLE:		
SKELETAL ANOMALIES:		
ATLANTO AXIAL DISLOCATION		
BASILAR INVAGINATION		
OCCIPITALISATION OF ATLAS		
KLIPPEL FEIL		
OS ODONTOIDEUM		
PLATYBASIA		
C1 ARCH HYPOPLASIA		
CONDYLAR HYPOPLASIA		

VA :

	I. OBSERVER		II. OBSERVER	
	RIGHT /	LEFT	RIGHT /	LEFT
TF PRESENT IN C1 ARCH				
TF PRESENT IN C2 ARCH				
ASYMMETRY OF VA				
PERSISTENT INTER SEGMENTAL VA:				
FENESTRATION:				
C1 ANTERIOR ARCH				
C1 POSTERIOR ARCH				
VA COURSE ON C1 POSTERIOR ARCH				

Addendum -2

S.no	Hospital number	Name	Age/sex	Occipitalization	Bony anomalies	VA Entry (type)
1	219473d	Maniksarkar	34/m	Left anterior arch occipitalization	BI,C2-3 KF, left C1 PA hypoplasia and left condylar hypoplasia	Ty 4 Ty 2a
2	361465d	Mohan murali	10/m	No occipitalization	AAD, KF (C2-3), left condylar hypoplasia	Ty 4 Ty 1b
3	256707d	Barun kumar	12/m	No occipitalization	Os od	Ty 1a Ty 1a
4	300258d	Surendranath	21/m	Complete occipitalization	BI,C2-3 KF, left condylar hypoplasia,C1 posterior arch rachischisis	Ty 2b1 Ty 2c
5	100526d	Ratan mani	43/f	No occipitalization	Os od	Ty 1a Ty 4
6	355857d	Jaikishore	40/m	No occipitalization	Os od	Ty 4 Ty 4
7	327755d	Tapas biswas	28/m	No occipitalization	AAD, C2-3 KF	Ty 4 Ty4
8	388811d	Preetam kumar	17/m	Complete occipitalization	BI, C2-3 KF, C1 posterior arch rachichisis	Ty 2b1 Ty 2b1
9	784920c	Alam mondal	31/m	No occipitalization	Os od	Ty4 Ty1b
10	379719d	Dilbashi debi	40/f	Right posterior Arch and left side complte occipitalization	BI, C2-3 KF, left condylar hypoplasia	Ty2b1 Ty2b1
11	158020d	Durga devi	43/f	No occipitalization	BI	Ty4 Ty 4
12	160195d	Gomathi	36/f	No occipitalization	Os od, C2-3 KF, C1 PA rachischisis	Ty4 Ty 4
13	232325d	Monica	15/f	No occipitalization	Os od, KF (c2-3), anterior arch rachischisis	Ty4 Ty4
14	319804d	Basmati devi	48/f	Complete occipitalization	BI,C2-3 KF	Ty2b1 absent
15	964900d	Sarirul islam	26/m	Complete occipitalization	BI, C2-3 KF	Ty2b1 Ty2b1
16	028580d	Jasbir kour	52/f	Complete occipitalization	BI, C2-3 KF	Ty2b1 Ty2b1
17	010878d	Dilipkumar	63/m	Right posterior Arch, left side complete occipitalization	BI, C1 PA rachischisis	Ty2b1 Ty2b1
18	115677d	Suresh sharma	40/m	Complete occipitalization	BI,C2-3KF	Ty1b Ty2b1

19	872558c	Manuranjan	6/m	Right side complete occipitalization	BI, C1 anterior and posteriora arch rachischisis,right C1 arch and right condylar hypoplasia,	Ty1a Ty4
20	788540c	Sahebkhan	13/m	Complete occipitalization	BI,(C2-3) KF	Ty2a Ty2a
21	616546d	Ranjith kumar	32/m	Complete occipitalization	BI,KF(C2-3, C5,6,7)	Ty1b Ty2c
22	064838d	Parichan dussad	52/m	No occipitalization	AAD	Ty4 Ty 4
23	348186d	Suresh	15/m	No occipitalization	Os od	Ty4 Ty 4
24	596199d	Anju sinha	48/f	Complete occipitalization	AAD, C2-3 KF	Ty1b Ty1b
25	666670c	Atindranath	41/m	Complete occipitalization	AAD	Ty2a Ty2a
26	744620c	Nasim alam	36/m	Complete occipitalization	BI,C2-3 KF	Ty2c Ty2c
27	292023d	Jagannath das	37/m	No occipitalization	Os od	Ty4 Ty4
29	942249c	Malliga	44/f	No occipitalization	Os od	Ty4 Ty4
30	798642d	Nikita bardhan	14/f	No occipitalization	Os od	Ty4 Ty4
31	019552d	Prabhumahat o	35/m	No occipitalization	Os od, anterior arch rachischisis	Ty4 Ty4
32	091761d	Gigijacob	45/m	Right side complete Occipitalization	BI, posterior arch hypoplasia	Ty2c Ty4
33	089401d	Chandra bali Singh	50/m	Complete occipitalization	BI,KF (2,3)	Ty2b1 Ty2b1
34	065000d	Subrata kumar	21/m	Complete left side occipitalization	BI,KF (2,3)	Ty2c Ty1b
35	735804c	Rinki kumari	12/f	Complete occipitalization	BI,KF (2,3),C1 anterior and posterior arch rachischisis	Ty1b Ty2b1
36	242150d	Palani samy	53/m	No occipitalization	AAD	Ty4 Ty4
37	010723d	Pintu chowdhury	18/m	Complete occipitalization	BI	Ty2c Ty2c
38	997395c	Shambhu sharan singh	27/m	Complete occipitalization	AAD, KF(2,3)	Ty2c Ty1b
39	601194c	Kamalesh	20/m	Complete occipitalization	KF, BI (2,3)	Ty2c Ty2a
40	219284d	Gopi	21/2	No occipitalization	Os od	Ty4 Ty4
41	060313d	Jeevan chakraborthy	41/m	No occipitalization	Os od	Ty4 Ty4
42	248432d	Shelinbhaji	13/m	No occipitalization	Os od	Ty4 Ty4
43	818309c	Ashok das	36/m	No occipitalization	Os od	Ty4 Ty4
44	110686d	Janamojyjan a	18/m	No occipitalization	Os od, anterior and posterior arch rechischisis	Ty4 Ty4

45	304878d	Bhobatoshdas	35/m	No occipitalization	AAD	Ty4 Ty4
46	938291c	Anada bardhan	45/m	No occipitalization	Os od	Ty4 Ty4
47	558670d	Abhijit mondal	19/m	Right side occipitalization	BI, posterior rachischisis	Ty2c Ty3
48	621075d	Manoj kumar	17/m	Complete Occipitalization	BI, Os od	Ty2c Ty2c
49	803710d	Vishal	12/m	No occipitalization	BI,KF (2-3),posterior arch rachischisis	Ty3 Ty3
50	612797d	Kausalya devi	28/f	No occipitalization	Os od	Ty4 absent
51	688737d	Keerthana	11/f	No occipitalization	Os od	Absent Ty4
52	704043d	Nikita kumari	7/f	No occipitalization	Os od, C1 anterior and posterior arch rachisichisis	Ty4 Ty4
53	777739d	Ayodhya sahu	59/m	Complete occipitalization	BI, KF(2-3)	Ty2c Ty2b1
54	475687d	Sagar mallick	12/m	No occipitalization	Os od	Ty4 Ty4
55	969130c	Sourya puskaran	6/m	No occipitalization	Os od	Ty4 Ty3
56	488690d	Manassaey raj	33/m	No occipitalization	Os od	Ty4 Ty4
57	633779d	Teibor usnney	24/m	Compelte occipitalization	BI	Ty2b1 Ty2b1
58	447968d	Jayachandran	23/m	No occipitalization	Os od	Ty4 Ty4
59	147912d	Sujit das	32/m	Complete occipitalization	Os od,(2-3), left condylar hypoplasia	Ty2b1 Ty2c
60	110416d	Bhargavi	25/f	No occipitalization	Os od	Ty4 Ty4
61	254847d	Ajit kumar	16/m	No occipitalization	BI, KF, C2-3, C3-T1 spina bifida, C3-4 rt lateral masses hypoplasia, anterior rachischisis	Ty1a Ty1a
62	849509d	Nilamani ray	55/m	Complete occipitalization	BI, KF (C2-3)	Ty2a Ty12b1
63	082069d	Sunny	15/m	Complete occipitalization	BI, right and left ondylar hypoplasia	Ty2a Ty1b
64	152895d	Vignesh	16/m	No	Os od, KF (c2-3)	Ty4 Ty4
65	697795c	Sanjeev kumar verma	36/m	No	Os od	Ty4 Ty4
66	875648d	Jegan	18/m	Complete	BI,C2-3 KF (c2-3)	Ty2b2 Ty2b2
67	850736d	Bikhni devi	41/f	Posterior	BI,KF (c2-3)	Ty2b1 Ty2b1
68	629193d	Bhavyasree	6/f	No	AAD,KF (c2-3)	Ty4 Ty4
69	216975d	Ritadevi	40/f	Complete	BI, KF (c2-3)	Ty2c Ty2c

70	863892d	Jancy rani	26/f	No	Os od	Ty4 Ty4
71	884305d	Saheer	26/m	No	Os od	Ty4 Ty4
72	879013d	Chandan bhuyan	22/m	Complete	BI	Ty2c Ty1b
73	930900d	Alka das	46/f	Right occipitalization	BI,C2-3 KF	Ty1a Ty4
74	846576d	Binod prasad chowrasia	37/m	Complete	BI,,right condylar hypoplasia	Ty2c Ty2a
75	015952f	Siril vincent	38/m	No	Os od	Ty4 Ty4
76	995196d	Mukesh kumar	38/m	Complete	BI, ant rachischisis	Ty1a Ty1b
77	792679c	Premsankara nnair	54/f	No	Os od	Ty4 Ty4
78	941845d	Arun prabhu	22/m	No	Os od	Ty4 Ty4
79	096722f	Kannammal	72/f	No	AAD	Ty4 Ty4
80	061429f	Sazad khan	32/m	Complete	BI	Ty 2b1 Ty2b1
81	071202f	Madan barnwal	36/m	Rightside occipitalization	BI,platybasia	Ty1b Ty4
82	988852d	Narendra kumar	47/m	Complete	BI,C2-3 KF	Ty1a Ty2b1
83	158083f	Ramranjan prasad	74/m	No	AAD	Ty4 Ty4
84	812628d	Asok kumar ghara	47/m	No	Os od	Ty4 Ty4
85	507968d	Anup kumar	44/m	Complete	BI, C2-3 KF	Ty2b2 Ty2b2
86	099869f	Prakash chandra	39/m	Right side posterior arch	BI, hypoplasia of left C1 arch, left occipital condyle	Ty2c Ty1b