Original Article www.pimr.org.in

DOI: 10.47799/pimr.1102.12

Radiological study of foramen arcuale: implications for screw insertion via posterior arch for fixation of C1 vertebrae in atlantoaxial instability using plain radiograph

Wasim Hiroli[1]*, Varsha Gadade[2]

[1]Assistant Professor, Department of Anatomy, Government Medical College, Baramati
[2]Assistant Professor, Department of Anatomy, Dr S.S. Tantia Medical College, Hospital and Research Center, Sri Ganganagar, Rajasthan

*Corresponding Author:
Wasim Hiroli, Assistant Professor, Department of Anatomy, Government Medical College, Baramati
E-MAIL: wasim.hiroli@gmail.com

Date of Submission: 20/07/2023 Date of Review: 01/08/2023 Date of Acceptance: 16/08/2023

ABSTRACT

Introduction: Foramen arcuale is an osseous structure forming a bridge from the superior articular process of the atlas that completely or partially encircles the vertebral artery. We retrospectively reviewed plain cervical radiographs as suggested by neurosurgeons, neurologists and orthopaedic surgeons for evaluation of cervical spine problems. When foramen arcuale is present, it creates a false impression of a broad posterior arch and can pose a risk during neurosurgery. The aim of this study is to investigate the prevalence of foramen arcuale in the Jalgaon & Baramati population.

Materials and Methods: 1255 lateral cervical spine radiographs were obtained from the radiology department, GMC, Jalgaon & GMC Baramati. The patient of which 655 (59.04%) were males and 600(31.42%) were females. Cases were classified as an incomplete and complete bony ridge.

Results: Overall prevalence of Foramen arcuale was 8.36%, with complete lesions in 3.50% and incomplete lesions in 4.86%. We noted an increasing percentage of patients with Foramen arcuale from the younger to the adolescent age group, with significantly greater prevalence in patients aged 15-30 years compared with the younger groups. Lesions were more common in males (59.04%) compared with females (31.42%), but no statistically significant difference between genders was detected for complete as well as incomplete foramen arcuale (p=0.95).

Conclusion: The foramen arcuale is a relatively common osseous structural variant therefore; surgeons should consider the risk of the presence of an FA prior to procedures on the atlas in each patient. So we suggest the identification of this variant by preoperative lateral radiograph as a starting point for C1 lateral mass for screw fixation via the posterior arch for atlantoaxial instability. If foramen arcuale is suspected or confirmed on a radiograph, 3D CT scanning should be considered for variations in size and shape of foramen arcuale and the possibility of injury to the vertebral artery.

KEYWORDS: Foramen arcuale (FA), Vertebral artery, Atlas, Atlantoaxial instability, Lateral cervical radiograph, Lateral mass screw

INTRODUCTION

Evaluation of anatomical landmarks is of immense importance for radiologists because any changes in these structures may be indexed to the underlying disease processes. Variations of such landmarks are common and often confusing. Extensive variations in the craniocervical junctions are very much common. [1, 2]Foramen arcuale is a bony prominence formed over the sulcus on the posterior arch of the atlas vertebra for the vertebral artery. It is an anatomical variant, when present the FA may partially or completely encircles the suboccipital nerve, vertebral venous plexus, and third segment of vertebral artery as it leaves the transverse foramen. [3]Therefore they must be studied with care to ensure adequate differentiation it from disease processes.

The Foramen arcuale is an abnormal small osseous bridge situated in posterior portion of the superior articular process and the posterolateral portion of the superior margin of the posterior arch of the atlas. In 1 to 15% of the population, a bony bridge may form thereby converting this groove into a foramen through which these structures pass. This bony arch is known as the foramen arcuale. [2]Until the surgical significance of the insertion of screws into the lateral mass of the atlas was recently reported, foramen arcuale had not been a topic of concern for spine surgeons. Young et al reported that during C1 lateral mass screw placement, the foramen arcuale can be mistaken for a broad posterior arch of the atlas could cause injury to the vertebral artery. [4]

Previous research provided an extensive list of names that have been used to describe this variation, which includes: arcuate foramen, foramen retroarticular, foramen sagittale, Kimmerle anomaly, Kimmerle deformity, pons posticus, pos-

terior atlantoid foramen, posterior glenoid process, posterior glenoid speculum, atlas bridging, canalis arteriae vertebralis, foramen atlantoideum posterior ponticulus, retroarticular ring, and retrocondylar bony foramen. [5–8] FA has been widely investigated in cadaveric [9] radiographic (lateral radiographs) [10] and CT studies. [11] CT provides high-quality imaging of bony structures, such as vertebrae allowing for accuracy of assessment similar to that obtained in cadaveric studies. [12, 13] However, lateral radiographs are less accurate and cannot fully assess the anatomical characteristics of an FA when it is present [12, 13], but can become baseline investigation.

The presence of an FA has been implied to have clinical significance. Tubbs et al [3] found that gross compression of the intraforaminal part of vertebral artery in cadavers when foramen arcuale present. The compression of vertebral artery may play a role in blood flow disturbances [14] thus contributing to the prevalence of neurological pathologies such as vertigo [11], migraine [14] or Barré-Lieou syndrome. [14]

Goel and Laheri introduced the C-1 lateral mass screw (C1LMS) insertion technique to treat atlantoaxial instability. In C-1 lateral mass screw (C1LMS) insertion, an approach is to start inserting a screw from the superior aspect of the posterior arch in proximity of the vertebral artery, venous plexus, and nerves to it. The presence of an FA can pose a risk for neurosurgeons by providing a false impression of a broader posterior arch when viewed dorsally. [15] Young et al reported that mistaking the foramen arcuale for a broad posterior arch of the atlas during C1 lateral mass screw placement could cause injury to the vertebral artery. [4] The surgeon may use large screws for insertion into the posterior arch, thus increasing the risk of injuring the vertebral artery, when the FA is not acknowledged. [3]

Considering the growing clinical importance of this entity, Comprehensive knowledge regarding the anatomy of the FA is critical for neurosurgeons to prevent damage to the vertebral artery during the C1LMS procedure. [3] The aim of this study was to provide the most comprehensive assessment to date of the prevalence of FA and its clinical significance. We retrospectively reviewed the cervical plain radiograph, which has been ordered by neurosurgeons and orthopaedic surgeon for evaluation of cervical spine problems, to investigate the prevalence of foramen arcuale in the Baramati population

MATERIALS & METHODS

This study was approved by the institutional review board of our medical colleges. We retrospectively reviewed 1455 cervical plain radiograph images of 1455 consecutive patients over 10 years of age who had visited our hospital due to cervical problems from April 2017 to August 2022. There were 655 men and 600 women, and the overall mean age was 28.36 ± 12.25 years (range; 10 - 54). The age of male patients ranged from 10 to 52 years (mean age ± standard deviation; 26.50 years ± 12.52) and from 9 to 55 years in females (24.60 years ± 13.70). The study was carried out at the Department of Radiology, GMC, Jalgaon & Baramati. Lateral cervical radiographs were retrieved from the archives of the Department of radiology and examined for foramen arcuale. In Lateral cervical radiographs, 200 images with poor visualization of the posterior arch of the atlas due to overlapping of the mastoid process or the occiput and radiographs with lateral inclination of the posterior arch of the atlas were excluded. Patients with congenital anomalies such as cleft palate and lip were not included in the study.

Patients with a history of injury or surgery in the cervical spine region were also excluded from the study. Cases with foramen arcuale were divided into two groups incomplete and complete bony ridge and the prevalence of lesions for age and sex group were determined. Statistical analysis: Data were collected regarding the patients' gender and age grouping as determined in the patients' electronic records. Descriptive statistics such as mean, standard deviation and percentage were used to display the data. For determining the significance of differences in the prevalence of complete and incomplete foramen arcuale between age groups and gender chi-square test was used.

RESULTS

Among the 1455 lateral cervical plain radiographs examined, 44 has complete (Figure. 1) and 61 had incomplete (Figure.2) bony ridge formation. Of the 44 complete bony ridges, 29 (65.90%) were males and 15 (34.09%) were females. Further, of the 61 incomplete bony ridges, 43 (70.49%) were males and 18 (29.50%) were females. A significant difference was found between age groups (x 2 =26.71, p<0.0001), as listed in Table 1Table 1.

. Significantly more male (59.04%) patients were identified with foramen arcuale (31.42%) than females (p=0.014) but no statistically significant difference between genders was detected for complete as well as incomplete foramen arcuale (x 2=0.003, p=0.95), as shown in Table 2. Table 2

Age	Total sample	Complete FA	Incomplete FA
<15	101	03 (2.97%)	07 (6.93%)
16-30	410	15 (3.65%)	22 (5.36%)
31-45	455	17 (3.73%)	25 (5.49%)
46-60	289	9 (3.11%)	7 (2.42%)

Table 1: Prevalence of variant by age group

Lateral cervical spine radiograph: showing normal spine with vertebrae

Lateral cervical spine radiograph: showing complete foramen arcuale

Gender	Total sample	Complete FA	Incomplete FA	Total variant
Male	655	29 (4.42%)	43 (6.56%)	62 (9.46%)
Female	600	15 (2.5%)	18 (3.00%)	33(5.50%)
Total	1255	44 (3.50%)	61 (4.86%)	105 (8.36%)

Table 2: Prevalence of variant sex-wise

Figure 1: Lateral cervical spine radiograph: showing complete foramen arcuale

Lateral cervical spine radiograph: showing Incomplete foramen arcuale

DISCUSSION

The presence of an FA is of clinical significance to radiologists, neurosurgeons and neurologists. The vertebral artery runs under this bony bridge and supplies blood to the brainstem and the cerebral cortex. The region of the FA is also the place where lateral mass screws are placed to treat atlantoaxial instability. [4, 16] When such a variant is not recognized, may give the neurosurgeon a pseudo impression of a widened posterior arch of the atlas, which can lead to arterial injury, stroke, and a fatal outcome. [4]The FA can be differentiated from a normal posterior arch during anatomical dissection—the FA broadens in the lateral direction and extends cranially, as compared to the normal posterior arch. However, during operation on the posterior arch of the atlas, it is not easy to distinguish between the FA and a wide posterior arch. Thus, a comprehensive study of the anatomy of the FA was much needed to expand the current knowledge base.

The area of complete FA was found to be smaller than the area of the transverse foramen of the atlas on the same side through which the vertebral artery traverses. [3]This may cause compression of the vertebral artery when the complete FA is present. Various studies have reported An association between a complete FA and neurological symptoms such as vertigo, migraine and Barré-Lieou syndrome, involving symptoms such as headache, retro-orbital pain, nausea and disturbances of phonation, swallowing, and vision,

Figure 2: Lateral cervical spine radiograph: showing Incomplete foramen arcuale

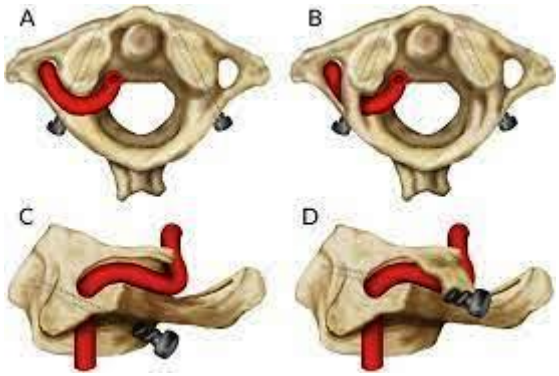

Figure 3: [11]Diagram showing C1 lateral mass screw fixation via posterior arch A : A: Atlas withoutan FA (superior view). B: Atlas with a completeFA (superior view). C: Atlas without an FA (lateral view). D: Atlas with a complete FA (lateral view).

has been reported in various studies, thus suggesting compression of the vertebral artery.[13, 17, 18]Moreover progressive improvement in symptoms has been noted after surgical removal of the bony bridge around the vertebral artery.[13] Screening for the presence of a complete FA in cases in which neurological symptoms suggestive of compression of the vertebral artery without other explanation is recommended.

Earlier studies on dry atlas vertebrae and lateral plain cervical radiographs showed inconstant data on the detection of foramen arcuale.[14, 19, 20]However, foramen arcuale has become an important entity that may be encountered during lateral mass screw fixation in treating atlantoaxial instability. Sometimes it may be a difficult procedure, as the region contains venous plexuses as well as the greater occipital nerve. To overcome these difficulties, some neurosurgeons have recommended that, if a broad posterior arch is present on the atlas, the insertion of the screw preferably be started from the dorsal aspect of the posterior arch instead of, at the junction of the posterior arch and the lateral mass or at the base of the lateral mass. The best indication for this modified screw trajectory into the posterior arch is the broad dorsal arch. The surgeon may make the mistake of considering the foramen arcuale as a broad dorsal arch and may insert the screw into the foramen arcuale damaging the vertebral artery. This can result in an injury to the vertebral artery,

and lead to stroke or even death by thrombosis, embolism, or arterial dissection. [4]

In the western subject, the prevalence of foramen arcuale has been reported to be between 5.1% and 37.8%. [4]In our study, the results (complete 6.8% + Incomplete 8.02%) were by Kendrick and Biggs [19] (complete + incomplete 15.8%), Pyo and Lowman et al [20] (complete + incomplete 12.7%) studies. Dugdale et al reported a higher frequency of Complete (14.8%) and incomplete (11.7%) foramen arcuale as compared to present and former studies. [21] The lower detection rate of the complete foramen arcuale in lateral cervical spine radiographs may be due to difficulties in visualization. Cederberg et al [22] studied foramen arcuale in 255 subjects using lateral cephalograph and found it in 11% of the cases. V Sharma et al [23] found the prevalence of foramen arcuale as 4.3% and also found male (5.33%) predominance over female (3.76%) in the population studies. In our study, complete foramen arcuale is seen in 9.12% of males and 4.38% of females. The difference could be assigned to the different origins of the population in both studies. We found increasing percentages of patients with Foramen arcuale from the youngest to the adolescent age group, with significantly greater prevalence in patients aged 15-30 years compared with the younger groups. In children older than 15 years a significantly greater number of complete bridges compared with incomplete foramen arcuale were found. This finding is suggestive of partial bridges progress may progress to complete lesions as age advances. [24]

other authors [25]have proposed that a regressive loss of the middle part of the complete bridge may lead to a partial or incomplete bridge. [26] Our results suggest that the presence of the foramen arcuale is a condition independent of age, as there is no statistically significant association between age and foramen arcuale so this variant should not be considered a pathological calcification or ossification of the lateral segment of the posterior atlantooccipital ligament. An ossification of functional significance, developed in other primates (Krishnamurthy et al., 2007) [9] to protect the vertebral artery, which may be susceptible to being damaged or compressed as a result of craniocervical dynamics.

CONCLUSION

The FA is a common osseous anatomical variant structure. Awareness of the presence of the complete variant before the surgical procedure involving atlas vertebrae in each patient is essential. We suggest preoperative baseline screening with lateral radiographs for detecting the presence of the FA. Clinicians should also look for the presence of the foramen arcuale in a patient with neurological symptoms suggestive of vertebral artery compression with no other explanations.

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How to cite this article: Hiroli W, Gadade V. **Radiological study of foramen arcuale: implications for screw insertion via posterior arch for fixation of C1 vertebrae in atlantoaxial instability using plain radiograph**. Perspectives in Medical Research. 2023;11(2):61-66
DOI: 10.47799/pimr.1102.12