Morphometric and radiological assessments of dimensions of Axis in dry vertebrae
A study in Indian population

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ABSTRACT
Background: The technique of intralaminar screw placement for achieving axis (C2) fixation has been recently described. The purpose of the study was to provide the morphometric and radiological measurements in Indian population and to determine the feasibility of safe translaminar screw placement in this population. To the best of our knowledge there is no study (cadaveric or radiological) done in Indian population to detect suitability of axis bone for laminar screw fixation.

Materials and Methods: 38 dry axis vertebrae from adult South Indian population were subjected to morphometric measurement and CT scan analysis. Height of posterior arch, midlaminar width (bilateral) in upper 1/3rd, middle 1/3rd and lower 1/3rd were measured using high precision Vernier Calipers. Each vertebra was subjected to a spiral CT scan (Philips brilliance 16 slice) thin 0.5 mm slices were taken and reconstruction was done in coronal and sagittal plane. Analysis was done on a CT work station. Using axial slices, sagittal cuts were reconstructed in plane perpendicular to the lamina at the mid laminar point and upper-middle and lower 1/3rd width of the lamina measured. Height of the posterior arch was measured in the sagittal plane. Intralaminar angle was measured bilaterally.

Results: Middle 1/3rd lamina was the thickest portion (mean 5.17 mm +/- 1.42 mm). A total of 32 (84.2%) specimen were having midlaminar width in both lamina greater than 4 mm, however only 27 (71%) out of them had spinous process more than 9 mm. CT scan measurement in middle and lower 1/3rd lamina was found to be strongly correlated with the direct measurement.

Conclusion: There is high variability in the thickness of the C2 lamina. As compared to western population, the axis bones used in the present study had smaller profiles. Hence the safety margin for translaminar screw insertion is low.

Key words: Axis fixation, laminar screws, translaminar screw, anatomy axis
MeSH terms: Bone screws, axis, cervical vertebral, anatomy and morphology, morphology

INTRODUCTION

The complex anatomic and biomechanical relationship between the axis and spinal column renders this region vulnerable to a variety of congenital, traumatic, infectious and degenerative pathologies.1-4 For this reason, rigid fixation of this area has been an area of great interest.

Wright1 described an intralaminar technique for achieving C2 fixation. Advantages of this technique include relative ease and the possibility of secure internal fixation in patients for whom transarticular or pedicle screws are not anatomically possible.2 Nakanishi et al.3 and Dorward Wright4 believe that C2 fixation utilizing bilateral, crossing C2 laminar screws represents an advantage to prior reported techniques of C2 fixation due to the elimination of the risk to the vertebral artery during C2 screw placement. This technique is simpler, not limited by the position of the vertebral artery in the body of C2 and may be applicable to a wider number of patients.3,4 Intraoperatively, it is relatively easy to verify the absence or presence of a dorsal breech, but it remains difficult to assess for a ventral violation. Clearly, avoidance of a canal violation is paramount to the safety of intralaminar screw placement.5 Studies have shown that biomechanically, this technique is comparable with posterior transarticular
and C1 lateral mass-C2 pedicle screw techniques. The only drawback to the technique is its requirement for intact and adequately sized lamina. Different cadaveric and dry bone studies have assessed the suitability, bony landmarks and useful parameters for safe screw placement. Determination of suitability for C2 screw placement is often judged from preoperative computed tomography (CT).

To the best of our knowledge, there is no study (cadaveric or radiological) done in Indian population to detect suitability of axis bone for laminar screw fixation. The purpose of the study was to provide the morphometric and radiological measurements and to determine the feasibility of safe translaminar screw placement in C2 vertebra.

**MATERIALS AND METHODS**

The anatomic specimens were provided by of Department of Human Anatomy. A total of 38 dry bone axis vertebrae from adult South Indian population were included in this study. To ensure that the vertebrae were intact and free from osteophytes, deformity or tumors, all specimen were inspected before measurements.

**Morphometric analysis**

Height of posterior arch, midlaminar width (bilateral) in upper 1/3rd, middle 1/3rd and lower 1/3rd were measured using high precision Vernier Calipers (Mitotoyo, Japan, with 0.005 mm accuracy) by a single neurosurgeon [Figure 1a]. In addition to it, maximum screw length was measured bilaterally. Screw entry points were on the surface of the dorsal arch of C2 with a trajectory aimed through the cancellous bone of the contralateral lamina. The maximal screw lengths were determined based on a technique using maximal bony purchase without violation of the contralateral bony cortex [Figure 1b]. Maximum height of the spinous process was also measured [Figure 1b].

![Figure 1: (a) Lateral view axis showing lamina divided into 3 equal parts (upper 1/3, middle 1/3, lower 1/3). (b) Maximum screw length-contralateral spinolaminar junction (bilateral 5 mm lateral to the midline, 4 mm below upper border on right side and 8 mm on left side) to the laminalateral mass junction](image)

**Computed tomography scan analysis**

Each vertebra was subjected to a spiral CT scan (Philips brilliance 16 slice) thin 0.5 mm slices were taken and reconstruction was done in coronal and sagittal plane. Analysis was done on a CT work station. Using axial slices, sagittal cuts were reconstructed in plane perpendicular to the lamina at the mid laminar point [Figure 2a] and upper-middle and lower 1/3rd width of the lamina measured as shown [Figure 2b]. Height of the posterior arch was measured in the sagittal plane [Figure 3a]. Intralaminar angle was measured bilaterally [Figure 3b].

**Statistical analysis**

Data were expressed as mean, median (standard deviation) and range. Spearman’s correlation was performed to find the correlation between morphometric and radiological measurements.

**RESULTS**

**Morphometric analysis**

Measurements from the dry bone morphometry are shown in Table 1. There was great variability in the laminar thickness. It was the thinnest in the upper 1/3rd (mean 3.45 mm ± 0.89 mm). Middle 1/3rd lamina was the thickest portion (mean 5.17 mm ± 1.42 mm). The lower
1/3rd portion is thicker as compared to upper 1/3rd or cranial portion (4.67 mm ± 1.19 mm). The mean screw length from the superior laminar entry site to the contralateral lateral mass was 27.99 mm ± 2.65 mm on right side and 28.00 ± 3.03 mm on left side. Our entire specimen had maximum screw length more than 2 cm. The mean cranialcaudal distance of the C2 spinous process was 10.77 ± 2.06 mm.

Many studies done on C2 vertebrae evaluating feasibility for C2 pedicle and C1–C2 transarticular screw have proposed that the minimum pedicular width required is 5.0 mm for 3.5 mm screw insertion, which leaves at least 0.5 mm of medial and lateral cortical wall thickness.9,10,11 Recent studies by Cassinelli et al. (2006, American)7 opined that since the screws are placed under direct visualization, a laminar thickness of >4.0 mm may be acceptable for safe translaminar screw placement. Wang8 emphasized the need for a 1 mm margin on each side for safe translaminar screw placement suggesting 5.5 mm as the minimum diameter required for safe 3.5 mm screw placement. Hence, we have analyzed our data keeping 4 mm, 5 mm and 5.5 mm as cut off values for safe 3.5 mm translaminar screw placement [Table 2].

Among 76 laminae, 67 (88.9%) lamina were having width <4 mm. A total of 32 (84.2%) specimen were having midlaminar width in both lamina >4 mm, however, only 27 (71%) out of them are having spinous process >9 mm. 3 (7.9%) out of 38 specimen have only one lamina whose width is >4 mm. In only 3 (7.9%) specimen, neither of the lamina had midlaminar width of >4 mm. Assuming the requirement of 4 mm laminar thickness 3 specimen and 3 lamina cannot accommodate a 3.5 mm translaminar screw. Five specimens could not accommodate bilateral translaminar screw as the height of the spinous process was <9 mm.9

### Table 1: Morphometric measurements (in millimeters) on dry anatomic specimens of C2 (n: 38)

| Measurements                                      | Mean±SD | Minimum | Maximum |
|---------------------------------------------------|---------|---------|---------|
| Mean width of right C2 lamina (upper 1/3)          | 3.56±0.86 | 1.74    | 5.65    |
| The mean width of left C2 lamina (upper 1/3)       | 3.33±0.91 | 1.75    | 5.43    |
| The mean width of right C2 lamina (middle 1/3)     | 5.28±1.31 | 1.37    | 8.87    |
| The mean width of left C2 lamina (middle 1/3)      | 5.06±1.29 | 1.74    | 8.40    |
| The mean width of right C2 lamina (lower 1/3)      | 4.69±1.23 | 2.45    | 8.40    |
| The mean width of left C2 lamina (lower 1/3)       | 4.54±1.21 | 2.19    | 6.85    |
| Height of posterior arch                           | 10.77±2.06 | 4.81    | 15.19   |
| Right screw length                                 | 27.99±2.65 | 22.61   | 32.77   |
| Left screw length                                  | 28.00±3.03 | 22.30   | 34.19   |

SD=Standard deviation

### Table 2: Morphometric analysis in relation to laminar width (in millimeters) and spinous process height for safe translaminar (3.5 mm) screw placement

| Combinations                                      | Width of lamina considered for safe placement (%) |
|---------------------------------------------------|--------------------------------------------------|
|                                                   | 4 mm     | 5 mm     | 5.5 mm   |
| Bilateral lamina equal to/more than cut off value with spine ≥9 mm | 27 (71.05) | 11 (28.9) | 6 (15.7) |
| Bilateral lamina equal to/more than cut off value with spine <9 mm | 5 (13.10)  | 2 (5.2)   | 2 (5.2)  |
| Only one lamina more than cut off value            | 3 (7.9)  | 14 (36.8) | 12 (31.5) |
| Bilateral laminae less than cut off value          | 3 (7.9)  | 11 (28.9) | 18 (47.3) |

If we consider a minimum requirement of 5 mm laminar thickness for safe placement of screw, 11/38 (28.9%) vertebrae will not be able to accommodate any screw and 14/38 (36.8%) specimens will be able to accommodate only unilateral laminar screw.

If we consider minimum requirement of 5.5 mm laminar thickness for safe placement of screw, 18/38 (47.3%) vertebrae will not be able to accommodate any screw. 12/38 (31.5%) vertebrae are viable for only unilateral screw placement. Only 8/38 (21.05%) specimens had bilateral laminar thickness >5.5 mm.

### Computed tomography scan analysis

The mean width of upper 1/3rd, middle 1/3rd and lower 1/3rd lamina measured was 4.05 ± 0.99 mm, 5.57 ± 1.28 mm and 4.67 mm ± 1.21 mm, respectively. The mean laminar angle on right side was 50.63° ± 4.07°, and on the left side was 51.47° ± 3.93° [Table 3].

Computed tomography scan data were also analyzed for critical laminar width of 4 mm, 5 mm and 5.5 mm as we had done in morphometric analysis [Table 4].
Computed tomography scan data suggest that 32/38 (84.2%) specimens were having bilateral laminae >4 mm and are suitable for bilateral translaminar 3.5 mm screw placement. Other 3/38 (7%) vertebrae were having bilateral laminar width >4 mm but the spinous process was <9 mm. One specimen was not fit for translaminar screw placement on both sides.

With the assumption of 5 mm as a safe laminar width, only 20/38 (52.6%) axis vertebrae were suitable to bilateral 3.5 mm translaminar screw placement. 10/38 (26.3%) bones were suitable for only unilateral screw placement, while 7/38 specimens were not fit for translaminar screw with this criteria.

If we consider minimum requirement of 5.5 mm laminar thickness for safe placement of screw as mentioned before. 14/38 (36.8%) specimens are suitable for bilateral translaminar screw placement, while in 15/38 (39.4%) bones, neither of the lamina was suitable for translaminar screw.

**Computed tomography scan vs. morphometric measurement**

The correlation between CT scan measurements and direct morphometric measurements was analyzed. Nonparametric bivariate correlation analysis with Spearman’s test was done [Table 5].

CT scan measurement in middle and lower 1/3rd lamina was found to be strongly correlated with the direct measurement. The correlation coefficient for both was 0.648 and 0.463, respectively.

**Discussion**

Rigid posterior fixation of the C2 vertebra has been most effectively accomplished using pedicle or C1–C2 transarticular screws.12,13 However, anatomic variations can place the vertebral artery at risk for injury during screw placement 18–23% of cases.14

Wright in 2004 proposed a new technique which involves the insertion of polyaxial screws into the laminae of axis vertebrae. In 2011 Wright and Dorward4 published their 7 years experience with this screw technique. They noted intraoperative ventral cortical disruption in 3 screws (2.9%) which did not require any further intervention. None of their case sustained a vascular or neurological injury from translaminar screw placement. They also reported a fusion rate of 97.6%. They have not used any outcome scale. However, among their 41-patient group with sufficient followup, 39 described their overall function as improved.

Further, Gorek et al.,6 used an odontoidectomized cadaveric model for atlantoaxial fixation and compared C2 translaminar screws to C2 pedicle screws. He found both the construct to be biomechanically stable. Although it is considered to be a relatively safe method, laminar violations have been reported with canal wall intrusion and ventral cortical breech.1 Knowing and understanding the lamina size, its trajectory and relationship between the lamina and nearby structures, especially the spinal cord and the vertebral artery are crucial for safe and effective fixation.

The present study has revealed that there is high variability in the thickness of the C2 lamina. It is the thinnest in the upper 1/3rd (mean 3.45 mm ± 0.89 mm). Middle 1/3rd lamina is the thickest portion (mean 5.17 mm ± 1.42 mm). The lower
1/3rd portion is thicker when compared to upper 1/3rd or cranial portion averaging (4.67 mm ± 1.19 mm). Hence, we opine that the middle 1/3rd laminar width can be used for convenient delivery of the screw. All subsequent analysis was done using middle 1/3rd laminar width.

Ma et al.9 (Chinese population, morphometric study) also showed that the C2 lamina is widest in its middle 1/3rd part. However, Sengolu et al. (2009, Turkish population, morphometric study) reported in their results that the lower 1/3rd part of the C2 lamina was the widest.

The minimum laminar width needed to allow for safe placement of a 3.5 mm screw varies in the literature. It ranges from 4 mm to 5.5 mm. Using the same criteria for analysis, we found out that 32 (84.2%) of the specimen are suitable for bilateral 3.5 mm translaminar screw with bilateral laminar width >4.0 mm. This data is comparable to Ma et al.9 who evaluated C2 anatomy relative to translaminar screw placement in an Asian Population. They found that 83.3% specimens were suitable for bilateral translaminar screw placement with a bilateral laminar thickness >4.0 mm. Similar study by Cassinelli et al.7 who evaluated the anatomic feasibility of C2 translaminar screw placement in African Americans and white population, showed that 93% of 420 adult C2 specimens had a laminar thickness >4.0 mm. The fewer number of specimens suitable for 3.5 mm screw fixation in present series and Asian population9 can be explained by the smaller size of specimen in this population.

Wang and Samudrala15 analyzed 38 cadaveric dry bones from an American population. They assumed the need for a 1 mm margin on each side for safe screw placement. Out of 38 specimens, 14 (36.8%) could not accommodate a 3.5 mm screw on at least one side; and overall 16/76 (21%) sides could not accommodate 3.5 mm screw. In the present study using the same criterion, 30/38 (78.9%) axis bones could not accommodate a 3.5 mm screw on at least one side; and overall 48/76 (63.1%) sides could not accommodate 3.5 mm screw. These comparisons strongly reveal that the axis vertebrae in the study population have significantly smaller dimension with respect to translaminar screw placement.

With reference to C2 pedicle and C1–C2 transarticular screw, there is abundant literature which proposes that if width or height of axis isthmus measures <5 mm; the placement of 3.5 mm screw becomes technically difficult. Various studies looking for feasibility of inserting C2 pedicle and C1–C2 transarticular screw identified that 18–23% of patients may not be suitable for inserting these type of screws on at least one side.11,16 In a CT-based study done on the same dry bones (as used in the present study), the authors had found that 31/94 (32.9%) of the C2 pedicle had width <5 mm (unpublished data). In the present study, 24/76 (31.5%) of the laminae had width of <5 mm.17 Hence, in the present study (Indian) population, C2 laminar screw does not appear to be more widely applicable as compared to C2 pedicle screw. This result is also in contrast to studies done in western population.4,7

The length (cranial-to-caudal distance) of the spinous process is another key factor for safe screw placement. To place bilateral 3.5 mm diameter screws, there has to be adequate space. We proposed that in addition to the 7 mm required for the 2 screws, one would need at least 2 more millimeters to place the screws; hence, the minimum spinous process height of 9 mm is required for bilateral safe translaminar screw placement. Similar criterion was given by Ma et al.9 Most of our specimens (31/38, 81.6%) are having cranial caudal distance >9 mm. However, 7 (18.42%) of the specimen are having spinous process height <9 mm. Ma et al.9 found that only 2.5% of the specimens have spine <9 mm. In the present study, 32 (84.2%) specimen were having midlaminar width in both lamina >4 mm, however, only 27 out of them had spinous process >9 mm, hence, only these specimen are suitable for bilateral translaminar screw placement on morphometric analysis. These results reveal that as compared to the Chinese population, a smaller percentage of Indian population might be suitable for bilateral translaminar screw insertion.

We have evaluated our specimens with CT scan also. Out of 38 specimen 35 (92.1%) specimen are having midlaminar width in both lamina >4 mm and 32 (84.2%) specimen have spinous process >9 mm. Two specimens have only one lamina whose width is >4 mm (both left). Only one specimen was found to have none of the lamina having midlaminar width >4 mm. As compared to 27/32 (71.05%) in our morphometric analysis, 32/38 (84.2%) specimen are fit for bilateral translaminar screw by CT scan (keeping the criteria of feasibility as 4 mm). The number of specimens, which will accommodate a 3.5 mm screw by keeping the criteria as 5.0 mm and 5.5 mm [Table 3]. The mean spinolaminar angle measured on CT by Dean et al.5 (2009, western population) was 42.45° ± 3.83° which was lower than mean laminar angle in present study which was (50.63° ± 4.07°) on right side, and (51.47° ± 3.93°) on the left side. We have noticed that direct measurement of the laminar diameter is lower than the CT scan measurement. Dean et al.5 had evaluated 84 adult spine and had shown high correlation between CT-based and cadaveric assessments of suitability for translaminar screws. However, similar difference between direct and CT scan measurement has
been documented in other studies done on thoracic and lumbar pedicles in Indian vertebrae.\textsuperscript{18}

The lamina of C2 merges with indistinct border with the spinous process on medial side and facet on lateral side. Hence determining the exact midpoint of lamina (CT scan or morphometry) without a distinct medial and lateral border is a difficult exercise. While doing CT scans, it is imperative to mention the exact way in which the slices have been taken (as we have done in the present study). There is an angle between inferior endplate of the C2 and the longitudinal axis of the C2 lamina. Hence, axial CT scan without reconstruction along the longitudinal axis of C2 lamina can cause incorrect measurement.\textsuperscript{19} These factors could contribute to the variability in results of several studies [Table 1]. Similar factors could have contributed to variability between CT scan and morphometric measurement, as seen in present study.

To the best of our knowledge, there has been no anatomic study to evaluate the feasibility of inserting C2 translaminar screw in Indian population. Moreover, we have done morphometric, CT scan analysis of the same specimens with reference to translaminar screw placement.

**Conclusion**

There is a high variability in the thickness of the C2 lamina. Middle 1/3\textsuperscript{rd} of the lamina is the widest part and can be used for convenient delivery of the screw. Using 5 mm as a cut off laminar width margin, 24/76 (31.5\%) laminae are not suitable for 3.5 mm screw placement. Using 4 mm as cutoff laminar width margin, 9/76 (11.8\%) of the specimen are not suitable for 3.5 mm translaminar screw. As compared to western population, the axis bones used in the present study (adult South Indian population) had smaller profiles. Preoperative CT scan is a reliable and accurate method to assess the feasibility of laminar screw.

**References**

1. Wright NM. Posterior C2 fixation using bilateral, crossing C2 laminar screws: Case series and technical note. J Spinal Disord Tech 2004;17:158-62.
2. Matsubara T, Mizutani J, Fukuoka M, Hatoh T, Kojima H, Otsuka T. Safe atlantoaxial fixation using a laminar screw (intralaminar screw) in a patient with unilateral occlusion of vertebral artery: Case report. Spine (Phila Pa 1976) 2007;32:E30-3.
3. Nakanishi K, Tanaka M, Sugimoto Y, Ozaki T. Posterior cervical spine arthrodexis with laminar screws: A report of two cases.
4. Doward IG, Wright NM. Seven years of experience with C2 translaminar screw fixation: Clinical series and review of the literature. Neurosurgery 2011;68:1491-9.
5. Dean CL, Lee MJ, Robbin M, Cassinelli EH. Correlation between computed tomography measurements and direct anatomic measurements of the axis for consideration of C2 laminar screw placement. Spine J 2009;9:258-62.
6. Gorek J, Acaroglu E, Berven S, Yousef A, Puttlitz CM. Constructs incorporating intralaminar C2 screws provide rigid stability for atlantoaxial fixation. Spine (Phila Pa 1976) 2005;30:1513-8.
7. Cassinelli EH, Lee M, Skalak A, Ahn NU, Wright NM. Anatomic considerations for the placement of C2 laminar screws. Spine (Phila Pa 1976) 2006;31:2767-71.
8. Wang MY. C2 crossing laminar screws: Cadaveric morphometric analysis. Neurosurgery 2006;59:ONS84-8.
9. Ma XY, Yin QS, Wu ZH, Xia H, Riew KD, Liu JF. C2 anatomy and dimensions relative to translaminar screw placement in an Asian population. Spine (Phila Pa 1976) 2010;35:704-8.
10. Mofakhar P, Fan X, Hurtvit CH, Black KL, Danilpou M. Long term survival in a child with a central nervous system medulloepithelioma. J Neurosurg Pediatr 2008;2:339-45.
11. Mandel IM, Kambach BJ, Petersilge CA, Johnstone B, Woo JU. Morphologic considerations of C2 isthmus dimensions for the placement of transarticular screws. Spine (Phila Pa 1976) 2000;25:1542-7.
12. Grob D, Magerl F. Surgical stabilization of C1 and C2 fractures. Orthopade 1987;16:46-54.
13. Goel A, Desai KL, Muzumdar DP. Atlantoaxial fixation using plate and screw method: A report of 160 treated patients. Neurosurgery 2002;51:1351-6.
14. Paramore CG, Dickman CA, Sonntag VK. The anatomical suitability of the C1-2 complex for transarticular screw fixation. J Neurosurg 1996;85:221-4.
15. Wang MY, Samudrala S. Cadaveric morphometric analysis for atlantal lateral mass screw placement. Neurosurgery 2004;54:1436-9.
16. Yoshida M, Neo M, Fujibayashi S, Nakamura T. Comparison of the anatomical risk for vertebral artery injury associated with the C2-pedicle screw and atlantoaxial transarticular screw. Spine (Phila Pa 1976) 2006;31:E513-7.
17. Pruthi N, Dawn R, Ravindranath Y, Maiti TK, Ravindranath R, Philip M. Computed tomography-based classification of axis vertebra: Choice of screw placement. Eur Spine J 2014;23:1084-91.
18. Datir SP, Mitra SK. Morphometric study of the thoracic vertebral pedicle in an Indian population. Spine (Phila Pa 1976). 2004 1;29:1174-81.
19. Xin-yu L, Kai Z, Laing-tai G, Yan-ping Z, Jian-min L. The anatomic and radiographic measurement of C2 lamina in Chinese population. Eur Spine J 2011;20:2261-6.

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