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Review

Chamberlain's line, clivus-canal angle, Welcker's basal angle, Boogaard's angle, and foramen magnum angle: a brief review for type B basilar invagination

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Introduction
Type B basilar invagination (BI) is an abnormality of the craniovertebral junction (CVJ). Since first descriptions occurred in the 18th and 19th centuries BI have gained remarkable clinical and surgical importance.
Objective
To describe usual craniometric parameters of assessment of type B BI and to discuss future perspectives of craniometry in the field.
Methods
This is a brief review of the literature on the CVJ parameters used for the BI diagnosis. Results: Although there are several craniometric parameters used in the diagnosis of BI, there are few studies on the validation of these parameters on radiography and volumetric images. Accuracy studies for Chamberlain' line, clivus-canal angle, Boogaard's angle, Welcker's basal angle, and foramen magnum angle occurred consistently at CT and MRI. Brachycephaly and reduced cranial height are strongly associated with type B BI.
Conclusion
The classical parameters of the Chamberlain's line, Boogaard's angle and clivus-canal angle are still important tests for the diagnostic evaluation of type B BI.

Keywords
Basilar invagination, Skull base, Accuracy, Cephalometry, Diagnostic imaging.

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Introduction

The craniovertebral junction (CVJ) is the transition region between the foramen magnum and the cervical spine, especially the first two cervical vertebrae, atlas (C1) and axis (C2). From the third month of intrauterine development, the occipital bone has four differentiated parts: basioccipital that forms the lower part of the clivus; exoccipital that delimit the foramen magnum laterally and have two articular masses (occipital condyles); and the supraoccipital that delimits the foramen magnum posteriorly and contains the cerebellar fossa (1).

The occipital bone as well as the other regions of the cranial base have a cartilaginous origin from synchondrosis (1). The skull base in humans is more flexed when compared to other primates, this seems to be related to adaptation to accommodate the brain (2). Spheno-occipital synchondrosis has been largely responsible for the flexion of the skull base between the basisphenoid and basioccipital (1, 2).

Dysfunctions in the development of spheno-occipital synchondrosis have been associated with type B basilar invagination (BI) (3, 4). The type B BI is a complex CVJ malformation characterized by basioccipital and exoccipital hypoplasia, which is often associated with posterior tilt of the odontoid process and Chiari malformation (5). In classical studies, the use of the term "basilar impression" or platybasia was very common for BI (6, 7). The clinical repercussion of BI is related to compression of the brainstem and spinal cord, constituting a major group of neurological diseases (5,6).

At the beginning of the 20th century, radiography began to be used in the BI (7). For a long time, plan radiographs were the only imaging method used in the CVJ evaluation (6, 7). During this period was difficult to make BI diagnosis, mainly due to the lack of specificity of the symptoms and the overlapping of CVJ structures in these image methods (8). With the advent of sectional imaging methods, the reconstruction of three-dimensional models has become a major tool to evaluate the cervical spine and skull base (9).

The period of the radiography was also marked by the description of several measures to assist in the radiographic evaluation of BI. Since then, many craniometric parameters of the radiographs have also been used in computed tomography (CT) and magnetic resonance imaging (MRI) (9), the latter being one of the most used in the CVJ evaluation (8). Anatomically, the measurements can be classified as primary (skull base) and secondary (cervical spine).

Chamberlain's line

The Chamberlain line was described in 1939 to evaluate the position of the odontoid process on plain radiographs (6). It is drawn from the posterior margin of the hard palate to the posterior margin of the foramen magnum (Figure 1). Previous descriptive studies have verified normal limits for this parameter, however there was no consensus in the literature regarding these values, probably due to the different imaging methods (10) and population characteristics.

The use of different limits of normality can be a bias for the BI diagnosis and lead to changes in its prevalence in different samples (11). In 2023, a systematic review found a mean normal of 0.63 mm below the Chamberlain's line for a normal sample population (11). The authors of this review also suggested that BI should be diagnosed in cases of any dens violation > 1.18 mm (11). In 2018, a diagnostic accuracy study at MRI found that a Chamberlain's line violation greater than

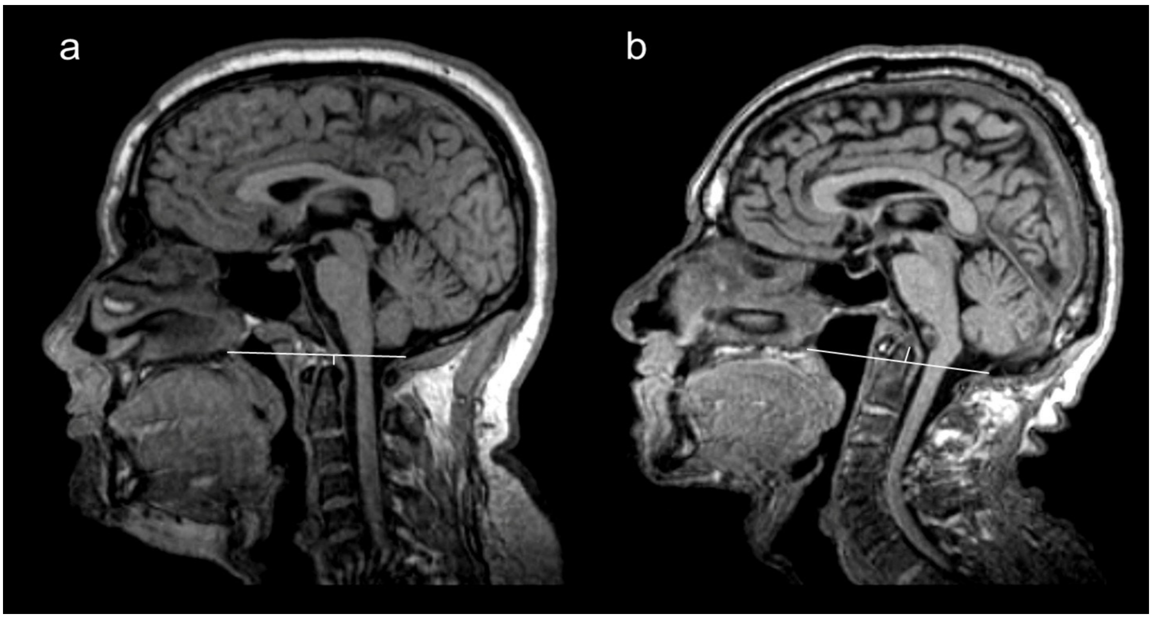

Figure 1. Mid-sagittal (T1 MPRAGE) in a control (left) and BI participant (right) showing the distance from the apex of the odontoid to the Chamberlain line. A. odontoid apex is 3 mm below Chamberlain's line. B. Dens violation is 9.3 mm above.

7 mm had an accuracy of approximately 90% (12).

Clivus-canal angle

Another classic parameter widely used in BI evaluation is the clivus-canal angle (Figure 2). This parameter is formed by a line tangent to the clivus and another tangent to the posterior portion of the odontoid process (10). Its normal range ranges from 150º in head flexion to 180º in extension. If this angle is less than 150º, there is a suggestion of brainstem compression (9). One study found in CT that clivus-canal angle values < 140º were suggestive of BI, with 82% and 88% of sensitivity and specificity, respectively (13).

The authors also observed the diagnostic performance of the clivus axial angle, a new diagnostic parameter that showed 83% and 89% sensitivity and specificity, respectively (13).

Henderson et al. (14) conducted a study with 10 patients with anterior brainstem compression. The results indicated that the correction of clivus-canal angle after surgery was related to a statistically significant clinical improvement. A similar study with a cohort of 5 children also provided similar evidence that the correction of these angle reduces the stress of the odontoid process on the brainstem (15).

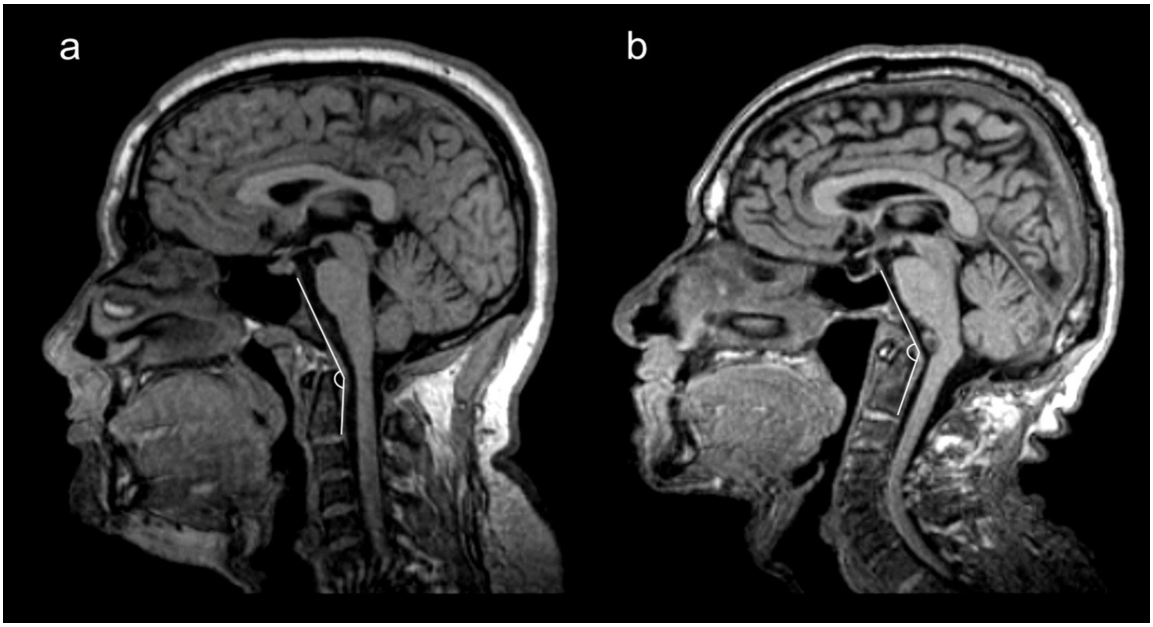

Figure 2. Mid-sagittal (T1 MPRAGE) in a control (left) and BI participant (right) showing the clivus-canal angle. A. Clivus-canal angle is 154.1º. B. Clivus-canal angle is 144.2º.

Welcker basal angle

Welcker's basal angle is formed by two lines: one from the nasium to the tubercle of the sphenoid bone and the other from this point to the anterior margin of the foramen magnum (Figure 3). Its average is 132º and values greater than 140 indicate the flattening of the skull base (platybasia) (10).

In CT study, Batista et al. (16) found in a group of healthy subjects that this angle ranged from 98.1º to 129.3º. In MRI, Frade et al. (17) found a mean of 128.9 ± 6.5º for randomized subjects with no diagnostic hypothesis of CVJ malformations. Nascimento et al. (12) found at MRI a cutoff criterion 142º for type B BI, with sensitivity and specificity of approximately 80%.

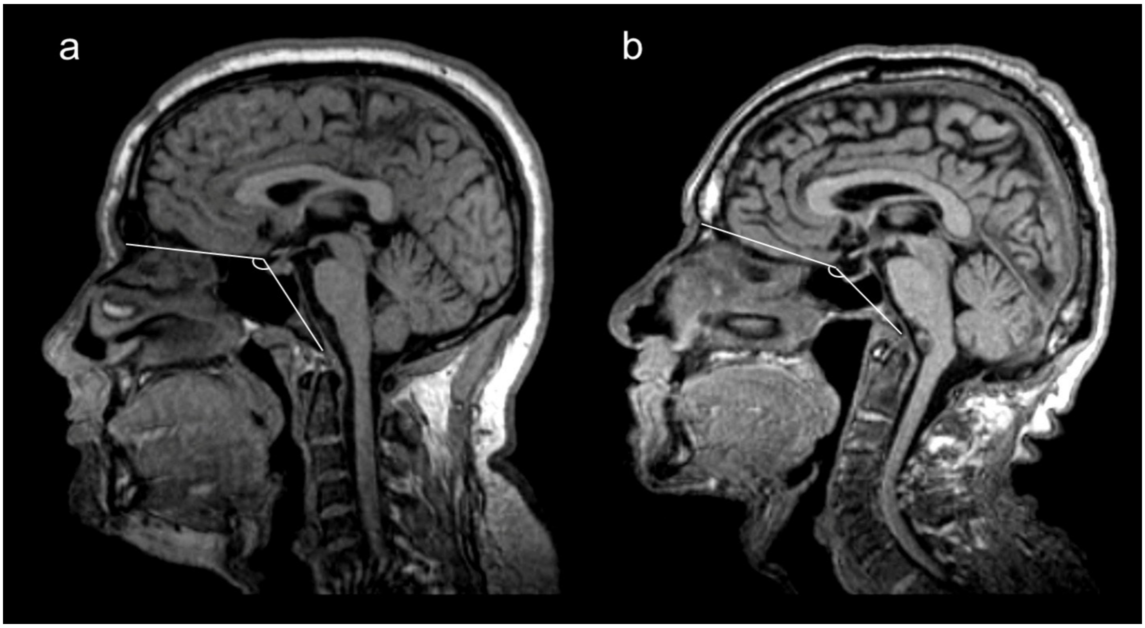

Figure 3. Mid-sagittal (T1 MPRAGE) in a control (left) and BI participant (right) showing the Welcker basal angle. A. Angle value is 129.5°. B. Angle value is 158º.

Boogaard's angle

The Boogaard's angle is formed by two lines, one tangent to the plane of the foramen magnum and the other tangent to the clivus, with the vertex of the angle at anterior margin of the foramen magnum (Figure 4) (18). This measurement normally is between 119.5° and 135°, and it is more obtuse in cases of type B BI due to clivus hypoplasia. Ferreira and Botelho (19) found that this angle showed a mean value of 181.9 ± 23.9º for type B BI and 126.2 ± 9.7º for the control group.

Other studies have sought to evaluate the clinical applications of the Boogaard's angle in the context of CVJ malformations. Data from the literature indicate that high values of this angle were associated with a volume reduction of the posterior cranial fossa (20) and cerebellar tonsil herniation in patients with Chiari malformation (21). In addition, the postoperative Boogaard's angle was an important predictor of the postoperative prognosis of BI in study by Peng et al. (22).

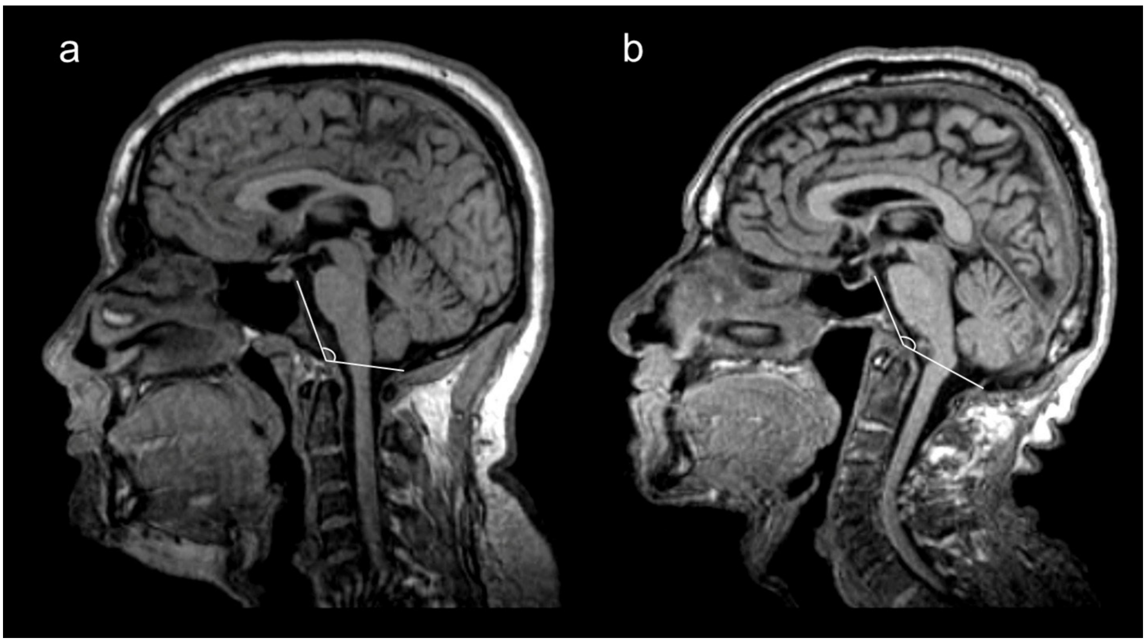

Figure 4. Mid-sagittal (T1 MPRAGE) in a control (left) and BI participant (right) showing the Boogaard's angle. A. Angle value is 121.4°. B. Angle value is 144.1º.

Foramen magnum angle

More recently, the foramen magnum angle was studied on MRI as a new measure to evaluate type B BI (Figure 5) (23). This parameter is formed by Chamberlain's lines and McRae's line, presenting the angle vertex at posterior margin of the foramen magnum. Using the ROC curve, with a value 17° as cutoff criterion the foramen magnum angle showed sensitivity 0.900 and specificity 0.854.

Thus, the foramen magnum angle can quantify the severity of type B BI by measuring the clivus hypoplasia, which causes an anterior inclination of the foramen magnum. This phenomenon is directly related to the alteration of the posterior cranial fossa, which can be with a volume reduction and possible herniation of the cerebellum and brainstem through the vertebral canal (23, 24).

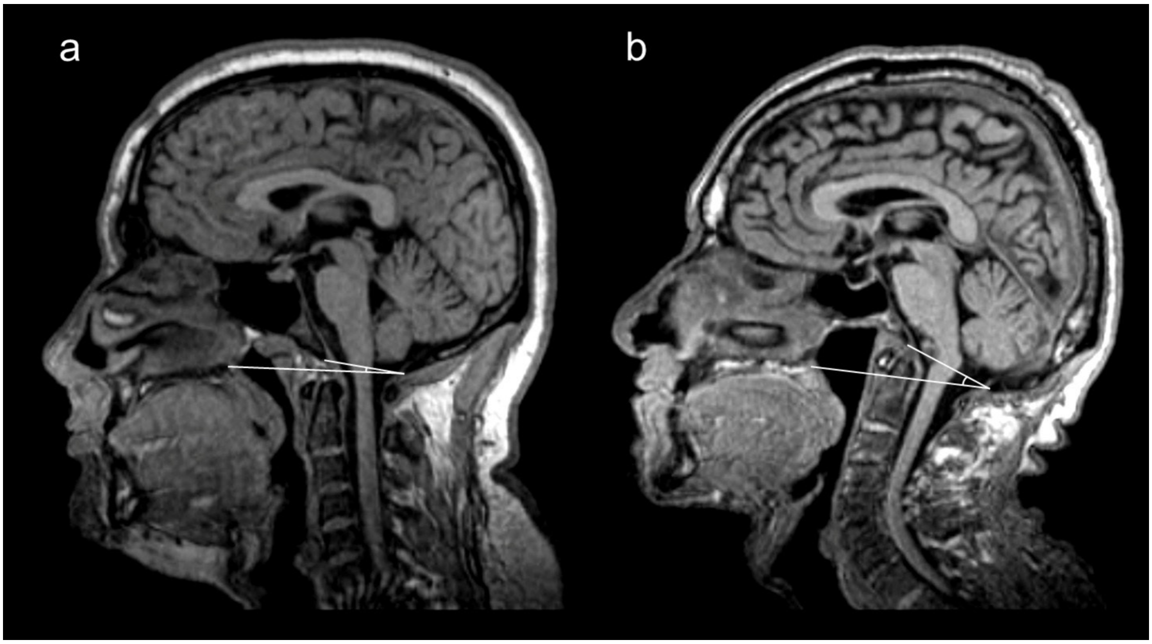

Figure 5. Mid-sagittal (T1 MPRAGE) in a control (left) and BI participant (right) showing the Boogaard's angle. A. Angle value is 7.8°. B. Angle value is 21.6º.

Future Perspectives in Craniometry

Although some CVJ measurements are almost 80 years old since their first description, only in the last 10 years have the first validations been performed on CT and MRI (12, 13). Recent studies also indicates that brachycephaly is often associated with the type B BI (25). The data indicate that cranial height is reduced in these patients, suggesting that the BI phenomenon can influence the course of cranial development and growth (25-27).

Finally, considering the guidelines established by STARD (28), the cutoff criterion for a diagnostic test should be determined considering concepts such as sensitivity, specificity, and accuracy. Thus, some directions are pertinent and deserve attention in future studies:

1. Diagnostic accuracy studies are still needed in isolated samples of type A BI, which are mainly characterized by atlanto-axial instability.
2. Researchers need to classify the patients in their studies according to each BI subtype, which are conditions completely different from each other.
3. Cranial phenotype (e.g., brachycephaly) can be a factor influencing the craniometric patterns of CVJ.
4. The Chamberlain's line, Boogaard's angle and clivus-canal angle are still important tests for the diagnostic evaluation of type B BI at CT and MRI.
5. STARD (Standards for Reporting Diagnostic Accuracy Studies) is recommended for future studies on craniometric accuracy for BI.

References

1. Shoja MM, Ramdhan R, Jensen CJ, Chern JJ, Oakes WJ, Tubbs RS. Embryology of the craniocervical junction and posterior cranial fossa, part I: Development of the upper vertebrae and skull. *Clin Anat.* 2018 May;31(4):466-487. Doi: 10.1002/ca.23049.
2. Botelho RV, Botelho PB, Diniz JM. Where does the cranial base flexion take place in humans? An Acad Bras Cienc. 2020;92(1):e20190825. Doi: 10.1590/0001-3765202020190825.
3. Botelho RV, Ferreira JA, Zandonadi Ferreira ED. Basilar Invagination: A Craniocervical Kyphosis. *World Neurosurg.* 2018;117:e180-e186. Doi: 10.1016/j.wneu.2018.05.233.
4. Nascimento JJC, Ribeiro ECO, Silva-Neto EJ, Araújo-Neto SA, Valença MM, Diniz PRB. Letter to the editor regarding "basilar invagination": It is not a single disease. *Eur J Radiol.* 2020 Nov;132:109280. Doi: 10.1016/j.ejrad.2020.109280.

5. Silva JAG, Santos, AA, Melo LRS, Araújo AF, Regueira GP. Posterior fossa decompression with tonsillectomy in 104 cases of basilar impression, Chiari malformation and/or syringomyelia. *Arq Neuropsiquiatr*. 2011;69(5): 817-823.
6. Chamberlain WE. Basilar impression (platybasis): a bizarre developmental anomaly of the occipital bone and upper cervical spine with striking and misleading neurologic manifestations. *Yale J Biol Med*. 1939; 11:487-496.
7. Schuller A. Zur Röntgen-Diagnose der basalen Impression des Schadels. *Wien. med. Wchnschr*. 1911; 61: 2593-2599.
8. De Vet, A. Basilar impresión of the skull. *J Neurol Psychiatry*. 1939; 3: 241- 250.
9. Jain N, Ritu-Verma, Garga UC, Baruah BP, Jain SK, Bhaskar NS. CT and MR imaging of odontoid abnormalities: A pictorial review. *Indian J Radiol Imaging*. 2016;26:108-119.
10. Smoker WR, Khanna G. Imaging the craniocervical junction.*Childs Nerv Syst*. 2008; 24:1123-45.
11. Joaquim AF, Evangelista Santos Barcelos AC, Daniel JW, Botelho RV. Chamberlain's Line Violation in Basilar Invagination Patients Compared with Normal Subjects: A Systematic Literature Review and Meta-Analysis. *World Neurosurg*. 2023 May;173:e364-e370. Doi: 10.1016/j.wneu.2023.02.057.
12. Nascimento JJC, Neto EJS, Mello-Junior CF, Valença MM, Araújo-Neto SA, Diniz PRB. Diagnostic accuracy of classical radiological measurements for basilar invagination of type B at MRI. *Eur Spine J*. 2019;28(2):345-352. Doi: 10.1007/s00586-018-5841-4.
13. Xu S, Gong R. (2016) Clivodens Angle: a New Diagnostic Method for Basilar Invagination at Computed Tomography. *Spine*. 2016;41(17):1365-1371. Doi: 10.1097/BRS.0000000000001509.
14. Henderson FC Sr, Henderson FC Jr, Wilson WA 4th, Mark AS, Koby M. Utility of the clivo-axial angle in assessing brainstem deformity: pilot study and literature review. *Neurosurg Rev.* 2018;41(1):149-163. Doi: 10.1007/s10143-017-0830-3.
15. Henderson FC, Wilson WA, Mott S, Mark A, Schmidt K, Berry JK, Vaccaro A, Benzel E. Deformative stress associated with an abnormal clivo-axial angle: A finite element analysis. *Surg Neurol Int*. 2010;16;1:30. Doi: 10.4103/2152-7806.66461.
16. Batista UC, Joaquim AF, Fernandes YB, Mathias RN, Ghizoni E, Tedeschi H. Computed tomography evaluation of the normal craniocervical junction craniometry in 100 asymptomatic patients. *Neurosurg Focus*. 2015;38(4):E5. Doi: 10.3171/2015.1.FOCUS14642.
17. Frade HC, França CCNL, Nascimento JJCD, Holanda MMA, Silva EJD Neto, Araújo SA Neto. Cranio-vertebral transition assessment by magnetic resonance imaging in a sample of a northeast Brazilian population. *Arq Neuropsiquiatr.* 2017;75(7):419-423. Doi: 10.1590/0004-282X20170071.
18. Boogaard, JA. De indrukking der grondrlakte van den schedel door de wervelkolom hare oorzaken en gevolgen. *Nederlands Tijdschrift voor Geneekunde*. 1865; 2: 81-108.
19. Ferreira JA, Botelho RV. The odontoid process invagination in normal subjects, Chiari malformation and Basilar invagination patients: Pathophysiologic correlations with angular craniometry. *Surg Neurol Int*. 2015;8;6:118. Doi: 10.4103/2152-7806.160322.
20. Alkoç OA, Songur A, Eser O, Toktas M, Gönül Y, Esi E, Haktanir A. Stereological and Morphometric Analysis of MRI Chiari Malformation Type-1. J *Korean Neurosurg Soc*. 2015;58(5):454-61. Doi: 10.3340/jkns.2015.58.5.454.
21. Dufton JA, Habeeb SY, Heran MK, Mikulis DJ, Islam O. Posterior fossa measurements in patients with and without Chiari I malformation. *Can J Neurol Sci*. 2011;38(3):452-5. Doi: 10.1017/s0317167100011860.
22. Peng L, Peng C, Yang F, Zuo W, Cheng C, Wang P, Zhang J, Li W. Comparative Analysis Between Machine Learning Algorithms and Conventional Regression in Predicting the Prognosis of Patients with Basilar Invagination: A Retrospective Cohort Study. *Turk Neurosurg*. 2023;33(4):665-675. Doi: 10.5137/1019-5149.JTN.36068-21.3.
23. Nascimento JJC, Silva LM, Ribeiro ECO, Neto EJS, Araújo-Neto SA, Diniz PRB. Foramen Magnum Angle: A New Parameter for Basilar Invagination of Type B. *World Neurosurg*. 2021;152:121-123. Doi: 10.1016/j.wneu.2021.06.028.
24. de Oliveira Ribeiro EC, de Barros DPM, do Nascimento JJC, da Silva Neto EJ, de Araújo Neto SA, Valença MM. Anatomical Implications of Chiari I and Basilar Invagination (Type B) in the IV Ventricle and Cisterna Magna. *World Neurosurg.* 2023;178:e750-e757. Doi: 10.1016/j.wneu.2023.07.154.
25. Nascimento JJC, Carreiro NMF, Oliveira GT, Ribeiro ECO, Holanda MMA, Neto EJS, Araújo-Neto SA. Relationship between basilar invagination and brachycephaly in Northeastern Brazil. *Eur J Radiol*. 2018;104:58-63. Doi: 10.1016/j.ejrad.2018.05.006.
26. Nascimento JJC, Silva LM, Ribeiro ECO, Neto EJS, Holanda MMA, Mello-Junior CF, Araújo-Neto SA, Diniz PRB. Investigating Type B Basilar Invagination Through Cephalic Indices. *World Neurosurg*. 2022;164:e1262-e1268. Doi: 10.1016/j.wneu.2022.06.007.
27. Botelho RV, Botelho PB, Hernandez B, Sales MB, Rotta JM. Association between Brachycephaly, Chiari Malformation, and Basilar Invagination. *J Neurol Surg A Cent Eur Neurosurg*. 2023;84(4):329-333. Doi: 10.1055/s-0041-1739503.
28. Bossuyt PM, Reitsma JB, Bruns DE, Gatsonis CA, Glasziou PP, Irwig L, Lijmer JG, Moher D, Rennie D, de Vet HC, Kressel HY, Rifai N, Golub RM, Altman DG, Hooft L, Korevaar DA, Cohen JF; STARD Group. STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies. *BMJ*. 2015; 28;351:h5527. Doi: 10.1136/bmj.h5527.

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