Parameters and Biomechanics of Cervical Sagittal Balance: A Concise and Precise Review

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Abstract

Cervical spine is a vital component of the human spine and it is different from other components. It is the most mobile part of spine and it not only holds the head load but also maintains head balance while in motion. It also helps to balance the thoracic spine which is just contrary to it. Thoracic spine is a rigid structure and its natural curve is kyphotic unlike cervical spine.

The equilibrium maintained by the cervical spine for head holding and balancing thoracic kyphosis is called cervical sagittal balance. Similarly, cervical spine also maintains the balance with lumbar spine and its lordosis. In fact, various components of the human spine are not individual parts from a function standpoint, they act simultaneously in a coordinated way to maintain the global balance so that human body remains in an equilibrium at any posture and position, this is what is called a sagittal balance. Cervical spine plays a vital role in maintaining the global balance of spine.

Many parameters have been identified to understand cervical sagittal balance. Surgical planning based on maintenance of sagittal balance with the help of these parameters gives the best outcome.

We hereby have tried to collect the maximum information about cervical sagittal balance which otherwise is not mentioned collectively elsewhere, and this will provide guidelines and surgical hints to a spinal surgeon.

Key words: cervical sagittal balance, cervical spine, parameters, spine

Introduction

The present modern life has led to significant rise in the spinal problems. Sitting with a forward head posture and neck bending is a common posture of many who do any kind of work in a sitting position. As a result, neck pain and subsequent cervical spine pathology is increasing in daily life.[1] In addition, it causes significant disability in daily life and is an economic burden for its management.[2] This is why currently researches and studies are focusing on principles of restoring the cervical spine anatomy and function.

Spine is the center of the human body and acts like fulcrum, especially in terms of posture of the body while in motion. Spine helps to maintain the posture of body, and this is achieved by the multiple curvatures that it naturally adopted such as cervical lordosis, thoracic kyphosis and lumbar lordosis. In addition, it is complemented by adjacent organs like the pelvis and hip joints.[3-8] Even though spine has various parts such as cervical, thoracic, lumbar and pelvic, they are not isolated individual parts, rather they have relationship connected among each other. Pelvic tilt and inclination affect lumbar lordosis, which then affects the curvature of the thoracic spine and finally the curvature of the cervical spine. There is a correlation between all these spinal regions, indicating that they are not independent of each other.[9-15] Therefore, a higher pelvic tilt or pelvic incidence causes a rise in lumbar lordosis, which in turn causes an increase in thoracic kyphosis, which further causes an increase in cervical lordosis. Therefore, cervical lordosis can be a compensatory and adaptive process in response to the global alignment of the spine, this is what is called cervical sagittal balance (CSB). Likewise, if there is primary pathology in the cervical spine, then the lumbar spine and pelvis compensate to maintain the spinal alignment.[10,11,16-18]

Normally, there is an equilibrium and balance in the sagittal and coronal plane of spine.[12] Sagittal balance of the spine has been found to be more vital than coronal balance as sagittal balance is more natural and anatomical while coronal balance is usually adaptive and pathological. This is especially important when making surgical plans for any kind of spinal surgery, especially the one aimed at correcting spinal deformity.[18-24] Therefore, in this article we will deal with the sagittal balance of the cervical spine.

Biomechanics of Cervical Spine

The cervical segment is one of the vital parts of the human spine and it functions to maintain the position of the head in relation to the body. Therefore, the cervical spine not only holds the

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head but also connects the head with the trunk and maintains the alignment of head mass with the pelvis and whole body.[14] As a result, an equilibrium is maintained between the head and rest of the body while in motion or in rest.

When the head moves in the sagittal plane paraspinal muscles of neck help to maintain balance by opposing the stress over the cervical spine.[25] Whenever there is cervical degenerative disease, the C7 tends to shift more anteriorly relative to the sacrum. As a result of compensatory mechanism, the center of head mass will be placed over the sacrum. When the deformity is corrected and the spinal alignment is restored, the compensatory cervical spine adjustment will also reverse. This is the simple yet vital principle of spinal alignment and CSB.[2 6-28] When there is any deviation in this alignment due to any reason, such as trauma, degeneration etc., there will be imbalance in the head load leading to more stress in the muscles of neck and thus leading to neck pain and other series of pathological processes causing spinal deformity.

Bearing of the head load by cervical spine is maintained and facilitated by the natural curvature of the cervical spine called lordosis. Lordosis of cervical spine, which is a highly mobile structure, also helps to balance the natural curve of thoracic spine (kyphosis) which is a rigid structure. The equilibrium required and provided by the cervical spine for head holding and balancing thoracic kyphosis is called CSB. The balance between the cervical spine and the thoracic spine, which are totally opposite to each other in terms of mobility and direction of curvature, is maintained by CSB.

However, varieties of pathological processes lead to alteration in CSB and thus treatment should aim to restore it. Therefore, parameters of CSB have been formulated which help to make surgical strategies to maintain the natural curvature of cervical spine. These parameters also help assess whether surgical treatment restored the cervical curvature and predict whether the patient will benefit.

In addition, cervical spine is more vulnerable to various degenerative and pathological processes due to its anatomical structure unlike lumbar spine.[28] This also suggests the importance of parameters of CSB.

Cervical spondylotic myelopathy is one of the most common pathologies of cervical spine that needs surgical management. Decompression alone and decompression combined with fusion are the main surgical procedures. Myelopathy is often associated with kyphotic changes of cervical spine. In that case, when surgical treatment is planned, it is important to consider the sagittal alignment of cervical spine. Only performing decompression, ventral or dorsal, without addressing kyphosis may not lead to the best possible outcome. Correcting the cervical kyphosis and hence restoring the cervical sagittal alignment in subaxial spine, above C7, by anterior or posterior approach, becomes mandatory in such situations.[27-29] This is the reason why it is essential to understand the concept of biomechanics and CSB of cervical spine which has distinct structure and function as compared to other parts of the spine. However, the normal value of these parameters is usually not uniform and often fluctuates due to various reasons. [22, 29-32]

Structure and function of Cervical Spine

The cervical spine is a complex structure connecting the head to the lower spine in such a way that the head freely moves around with perfect equilibrium. In addition to protecting the spinal cord, cervical spine functions to hold the mass of the head, to allow it a wide range of motion and to maintain the balance of the whole trunk and human body. Moreover, the upper cervical spine that includes the first and second cervical vertebrae (C1 & C2), craniocervical junction (C0-C1 joint) and C1-C2 joint, is again a unique piece. It does not have intervertebral disc and ligamentum flavum, has distinct bony anatomy and joints from occiput (C0) to C2 and is fixed in a complex ligamentous structure.

The cervical spine is the most mobile part of the spine and provides about 90° of rotation, 80-90° of flexion, 70° of extension and 25-45° of lateral flexion. Among these movements about three fifths (60%) of total cervical rotation and two fifths (40%) of total cervical flexion and extension occur at the level of upper cervical spine (C0-C1-C2). C1-C2 has higher mobility than C0-C1 where movement is restricted due to occipital condyle and C1 socket anatomy. C0-C1 provides about 15-20° of flexion and extension. Axial rotation is limited, and lateral flexion is almost nil at this level. Whereas at C1-C2 level, the axial rotation is maximum, about 50°, followed by flexion/extension and lateral flexion. The lower cervical spine provides significant flexion and extension whereas rotation and lateral flexion are limited at this segment due to posteriorly inclined facet joints.

The load of the head is supported by occipital condyles and is transferred to the lateral masses of C1 via atlantooccipital joint. The lateral masses of C1 are much larger, as compared with those of other cervical vertebrae, to bear the load of the head. The load is then transferred to the vertebral body of C2. From the atlantoaxial joint the head load is then transferred to the three columns of subaxial spines. In cervical spine the anterior column bears about one third of the head load whereas two thirds of the load is born by the middle and posterior columns. This is in contrary to the lumbar spine where the maximum load, more than two thirds, is born by anterior column and the posterior columns bear only a small portion.

Cervical spine joins thoracic spine which are two contrast structures. The cervical spine is highly mobile whereas thoracic spine is almost fixed. In addition, cervical spine has anterior curvature (lordosis) whereas thoracic spine has posterior curvature (kyphosis). Despite this fact, there exists a balance between these two structures, and this is by virtue of what is known as CSB.

Cervical sagittal balance (CSB), cervical lordosis (CL) and cervical kyphosis (CK)

The cervical sagittal balance or alignment is the concept of relative position of head or occiput in relation to neck or thoracic inlet. It is the concept of how cervical spine is postured or positioned in the sagittal plane. If there is an imbalance or malalignment in the cervical spine posture it can lead to progressive cervical spine deformity, further malalignment and further deformity[25, 33] ultimately leading to the deformity of lower spine and hip joints and to the poor health related quality of life (HRQOL).

Well-maintained cervical lordosis (CL) is essential for CSB as its malalignment leads to chronic neck pain, headache and other spinal pathologies like radiculopathy and myelopathy. Cervical lordosis changes with age, sex, degenerative changes and other associated pathologies. [25, 30, 34, 35]

Cervical kyphosis (CK) is the condition opposite to cervical lordosis. It occurs when there is loss of normal lordosis and progressive deformity of cervical spine leading to forward bending of neck, opposite to the normal direction. CK is caused by various factors such as progressive degenerative changes, surgical procedures, trauma etc. and it makes cervical spine more rigid leading to cord and nerve compression.

Parameters of CSB

There are numerous parameters based on radiographic measurements used to assess the CSB and thus cervical alignment and to predict the outcome after surgery (Figure 1).[21, 23, 33, 36-40]

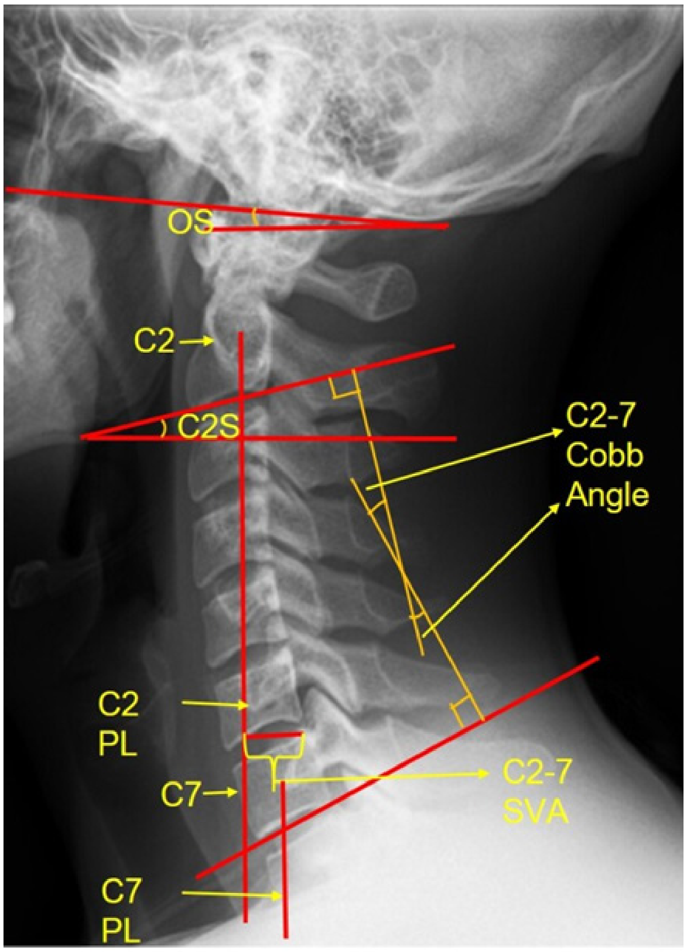

Figure 1: Figure showing parameters of CSB; C2-7 Cobb angle, C2-7 Sagittal Vertical Axis (SVA), C2 slope (C2S), Occipital slope (OS), C2 Plumb line (PL)

1.Cervical 2-7 (C2-7) Cobb Angle: Cobb angle is one of the most used parameters in the spine at different levels, mainly at cervical and thoracic level. It was named after an American orthopedic surgeon John Robert Cobb and is used to measure the spinal curvature such as quantification of lordosis, kyphosis and scoliosis. In simple language, it is the angle between the tangential lines of lower endplates (EP) of uppermost and lowermost vertebrae being considered. It is also called cervical lordotic angle which measures cervical lordosis. Therefore, C2-7 Cobb angle is the angle between tangential line passing through the LEP of C2 and that passing through the LEP of C7. It is measured by drawing perpendicular lines from tangential lines of LEP of C2 and C7. The angle made by the intersection of two perpendicular lines is C2-7 Cobb angle. It indicates the degree of lordosis of cervical spine and is used to determine its sagittal alignment. C2-7 Cobb Angle is also used to measure the cervical range of motion by taking a dynamic X-ray and measuring the angle in flexion and hyperextension positions. Normal C2-7 Cobb angle is about 20°-35°. More is the Cobb angle higher is the lordosis. That means less Cobb angle suggests kyphosis or loss of lordosis. In other words, the positive value of C2-C7 Cobb angle means lordosis and the negative value means kyphosis. Similarly, Occiput (C0)-C2, C1-2, C0-7 and C1-7 cobb angles can also be considered. The cobb angles can be measured manually using the X-Ray images or by the automatic system using software.[41]

2.C2-7 sagittal vertical axis (SVA): It is another commonly implemented measure of cervical sagittal balance. SVA estimates the relative anteroposterior distance between the different segments of the spine.[22,33,42] The cervical (C2-7) SVA is calculated by measuring the horizontal distance between the posterosuperior corner of the C7 vertebral body and a plumb line (PL) dropped from the centroid of C2. Therefore, it measures the distance between upper segment and lower segment of the cervical spine and thus estimates cervical lordosis. The higher the SVA the more cervical lordosis and vice versa. In general, C2-7 SVA <4 cm is considered normal and greater SVA has been shown to be associated with greater neck disability index (NDI).40 SVA of the whole spine can also be measured to assess its sagittal balance. SVA of the whole spine is the distance between the C7 plumb line and the posterosuperior corner of first sacral vertebra (S1). Similarly, C2-S1 SVA can also be measured.

3.C1-7 SVA: C1-7 SVA is defined as the distance between a PL dropped from the center of the C1 anterior arch and the posterosuperior corner of the C7 vertebral body.

4.C2 slope (C2S): C2S is a parameter to explain cervical deformity. It is an angle between the LEP of C2 and a horizontal line passing through it and is considered equivalent to T1 Slope (T1S) of thoracic spine. C2S has been found to be significantly correlated with the upper cervical and subaxial cervical spine alignment.24 It has been found that C2S=T1S-CL (T1S minus CL) is thus a significant marker of cervical deformity including occipitocervical with cervicothoracic spine.

5.Occipital Slope (OS): It is the angle between the McGregor line and horizontal line. Its normal value is about 23°.29

6.C2 and C7 PL: C2 and C7 PL are the vertical line drawn from the centroid of the C2 or C7 vertebral bodies. Distance between these PLs (C2-7) is 15-17 mm. Higher C2-7 PL means more cervical curvature or lordotic. Less C2-7 PL means more straightening of the cervical spine due to loss of lordosis.

7.C7 SVA: The distance of C7 PL from the posterior sacral endplate is C7 SVA and it determines sagittal balance. Balanced spine is the one with C7 SVA <5cm and unbalanced spine is with C7 SVA >5cm. C7 SVA is also used to assess global spinal sagittal balance. If C7SVA is more than 5 cm it is called positive sagittal balance. In this case, there is forward stooping posture due to failure in compensation of sagittal balance leading to chronic and severe back pain. This can be corrected by appropriated surgical treatment which can restore the spinal curvature.

8.Cervicothoracic junction (CTJ) and its parameters: The CTJ is comprised of cervical and thoracic spine and a rigid bony ring called thoracic inlet. Thoracic inlet is formed by the first ribs on either side, T1 vertebra and upper end of sternum. The curvature of the cervical spine is influenced by multiple factors including the discs between C2 and C7, the ligaments connecting the vertebrae and the structures of the cervicothoracic junction (CTJ), which usually includes C7 and the first thoracic vertebra (T1). Therefore, the CTJ parameters (Figure 2) also play a vital role in cervical spinal pathology. At the level of CTJ cervical spine transitions to thoracic spine which is a rigid structure with an opposite curvature. Same as pelvis and its orientation has influence on the lumbar lordosis, thoracic inlet also has its effect on the cervical spine and its curvature. This sudden transition from cervical to thoracic spine, to a completely opposite structure in terms of mobility and direction of curvature, puts a significant amount of stress on CTJ and cervical spine in both static and dynamic posture. This stress is taken care of naturally and thus an individual remains asymptomatic. But when this natural mechanism fails due to any reason, pathological processes progress in a vicious cycle.[44,45]

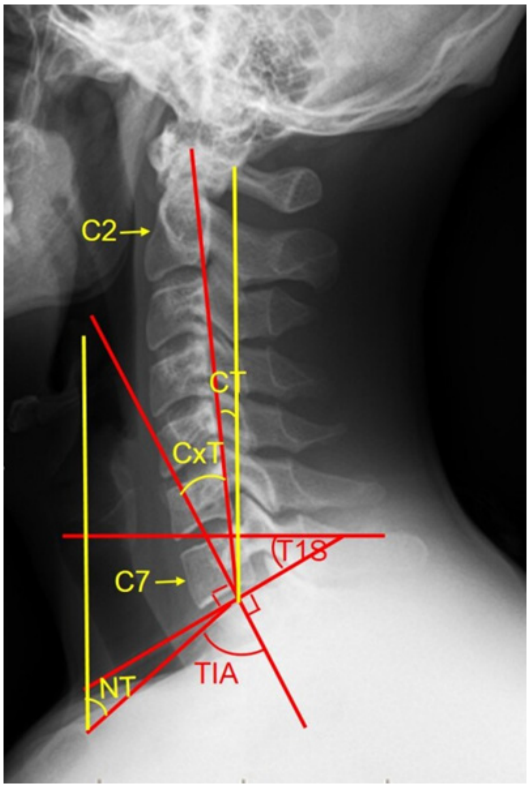

Figure 2: Figure showing parameters of CTJ; Thoracic Inlet Angle (TIA), T1 Slope (T1S), Neck Tilt (NT), Cranial Tilt (CT), Cervical Tilt (CxT)

a.T1 Slope (T1S): The slope of every vertebral body contributes to the curvature of spine and thus is one the important parameters of CSB.[46,47] Sagittal imbalance of the spine is an important factor leading to development of clinical symptoms and degenerative disease. It directly influences the perioperative care and post operative outcome. T1S is an angle between the upper endplate (UEP) of T1 and a horizontal line passing through it. A large T1S leads to more lordosis of cervical spine and vice versa. The smaller the T1S the more possibility of loss of lordosis and kyphosis of cervical spine. In other words, an increased T1S can occur due to hyperkyphosis of upper thoracic spine leading to compensatory hyperlordosis of cervical spine. This leads to the development of various kinds of pathological changes in cervical spine. T1S in relation to cervical spine is considered equivalent to sacral slope in relation to lumbar spine. As higher sacral slope and pelvic incidence leads to higher lumbar lordosis, higher T1S leads to higher cervical lordosis to maintain the CSB. It has been found that T1S has a significant correlation with C2-7 SVA, higher is the T1S more will be the C2-7 SVA.[42,48] As cervical lordosis is influenced by thoracic kyphosis T1S helps in evaluating and determining cervical stability. T1S also serves as the predictor of post laminoplasty outcome in case of ossified longitudinal ligament or severe spinal canal stenosis.[12]

b.Thoracic Inlet angle (TIA): TIA is the angle made by the line drawn from the midpoint of the T1UEP perpendicular to it and the line joining the T1UEP and upper end of sternum. There is a very good correlation among T1S, TIA, thoracic kyphosis and cervical SVA. The larger the TIA and T1S the more cervical lordosis is.[48]

c.Neck Tilt (NT): NT is the angle formed by a vertical line from sternum tip and the line drawn from the center of C7UEP to the tip of sternum. It is an angle between two lines both originating from the upper end of the sternum, one being a vertical line and the other connecting to C7UEP. Geometrically, TIA=T1S + NT. NT signifies TIA and therefore it is low when there is head forward posture.

d.Cranial Tilt (CT): Cranial tilt is another parameter which helps in assessing the cervical sagittal balance. It is the angle made by a line which extends from the center of T1UEP to the odontoid tip and a vertical PL passing through it.

e.Cervical Tilt (CxT): It is the angle made by a line that extends perpendicularly through the center of T1UEP and a line that extends from the center of T1UEP to the odontoid tip.

9.Harrison posterior tangent method: It is one of the methods that have been developed and formulated to measure the extent of cervical lordosis. In this method tangential or parallel lines are drawn along the posterior margins of bodies of all the vertebrae from C2 to C7, and all the angles are added to obtain the cervical curvature.

10.Jackson physiological stress lines: It is a modified and simplified version of Harrison posterior tangent method. Tangential lines are drawn along the posterior margin of C2 and C7 vertebral bodies and then the angle made by the intersection of these lines (Figure 3) is measured. This angle can be compared before and after surgery to assess the restoration of cervical lordosis.

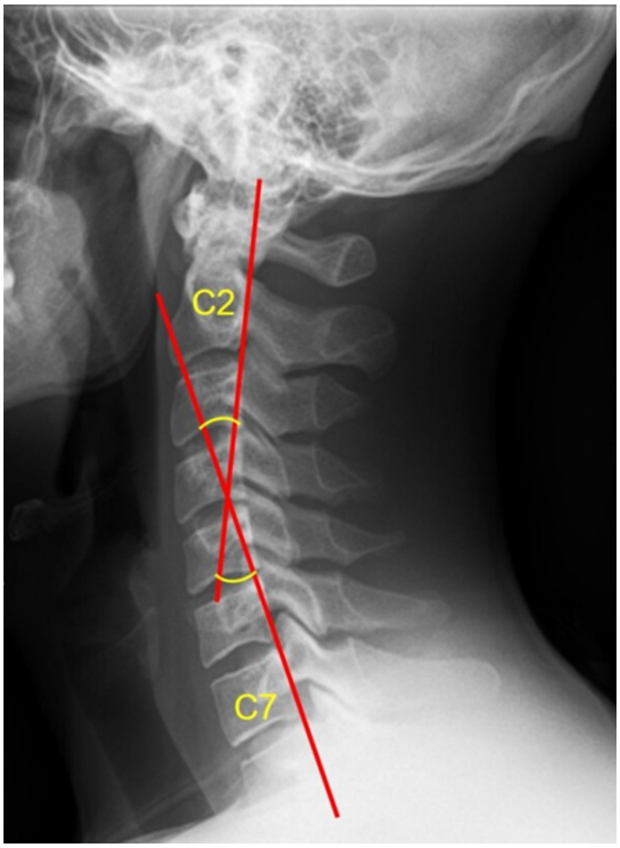

Figure 3: Figure showing Jackson physiological stress lines and angle

11.K-line: It is the vertical line which joins the mid points of anteroposterior diameters of spinal canal of C2 and C7.[49,50] In normal curvature of cervical spine, K-line lies almost in the middle of spinal canal and is called K-line (+) positive. It means K-line is not crossed by the anterior limit of spinal canal i.e. vertebral bodies or any pathology in the spinal canal such as ossified ligament (OPLL). It indicates the normal curvature or lordosis of the cervical spine. But in cervical spinal canal stenosis, especially due to OPLL, if the K-line is touched or crossed by the anterior limit of spinal canal, then it is called K-line (-) negative. It indicates the spinal canal is quite narrowed and there is significant loss of cervical lordosis. It not only helps to evaluate the cervical spine curvature before surgery but also helps to prognosticate and evaluate the sufficient decompression after surgery.

Conclusion

Various parameters of cervical sagittal balance have been explained in this review. Spine is a single organ with multiple vital components and must maintain sagittal balance to function properly. Multiple factors including joints of spine, intervertebral disc, paraspinal muscles, pelvis, hip joints etc. play vital role in the maintenance of this balance. The parameters have been developed to assess the exact pathology of spine which are well correlated with clinical symptoms and radiological findings. Thus, parameters help provide the necessary surgical or non-surgical management. They also help assess the post operative status and restoration of the spinal curvature and efficacy of treatment. Lack of knowledge about the parameters fails to judge spinal problems and provide the appropriate treatment leading to poor clinical outcomes.

References

1. Hoy D, March L, Woolf A, Blyth F, Brooks P, Smith E, et al. The global burden of neck pain: estimates from the global burden of disease 2010 study. Ann Rheum Dis, 2014;73(7), 1309-15. https://doi.org/10.1136/annrheumdis-2013-204431
2. Hoy DG, Protani M, De R, Buchbinder R. The epidemiology of neck pain. Best Pract Res Clin Rheumatol, 2010;24(6), 783-92. https://doi.org/10.1016/j.berh.2011.01.019
3. Cheung JPY. The importance of sagittal balance in adult scoliosis surgery. Ann Transl Med 2020;8(2), 35. https://doi.org/10.21037/atm.2019.10.19
4. Kim D, Davis DD, Menger RP. Spine Sagittal Balance [Internet]. StatPearls, StatPearls Publishing LLC, 2024. Available from: https://www.ncbi.nlm.nih.gov/books/NBK534858/
5. Paholpak P, Vega A, Formanek B, Tamai K, Wang JC, Buser Z. Impact of cervical sagittal balance and cervical spine alignment on craniocervical junction motion: an analysis using upright multi-positional MRI. Eur Spine J, 2021;30(2), 444-53. https://doi.org/10.1007/s00586-020-06559-5
6. Lee SH, Kim KT, Seo EM, Suk KS, Kwack YH, Son ES. The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. J Spinal Disord Tech, 2012;25(2), E41-7. https://doi.org/10.1097/BSD.0b013e3182396301
7. Lee SH, Kim TH, Kim SW, Rim HT, Lee HS, Kim JH, et al. The Sagittal Balance of Cervical Spine: Comprehensive Review of Recent Update. J Korean Neurosurg Soc, 2023;66(6), 611-7. https://doi.org/10.3340/jkns.2023.0146
8. Ling FP, Chevillotte T, Leglise A, Thompson W, Bouthors C, Le Huec JC. Which parameters are relevant in sagittal balance analysis of the cervical spine? A literature review. Eur Spine J, 2018;27(1), 8-15. https://doi.org/10.1007/s00586-018-5462-y
9. Sakaura H, Ikegami D, Fujimori T, Sugiura T, Yamada S, Kanayama S. Postoperative Changes of Spinopelvic Sagittal Parameters after Cervical Laminoplasty for Cervical Spondylotic Myelopathy. Clin Spine Surg, 2024;37(3), E119-23. https://doi.org/10.1097/bsd.0000000000001545
10. Miyazaki M, Ishihara T, Notani N, Kanezaki S, Tsumura H. Relationship of T1 slope with loss of lordosis and surgical outcomes after laminoplasty for cervical ossification of the posterior longitudinal ligament. Clin Neurol Neurosurg, 2018;164, 19-24. https://doi.org/29145042 DOI: 10.1016/j.clineuro.2017.11.007

11. Kim B, Yoon DH, Ha Y, Yi S, Shin DA, Lee CK, et al. Relationship between T1 slope and loss of lordosis after laminoplasty in patients with cervical ossification of the posterior longitudinal ligament. Spine J, 2016;16(2), 219-25. https://doi.org/10.1016/j.spinee.2015.10.042
12. Abelin-Genevois K. Sagittal balance of the spine. Orthop Traumatol Surg Res 2021;107(1S):102769. Http//: DOI: 10.1016/j.otsr.2020.102769
13. Le Huec JC, Thompson W, Mohsinaly Y, Barrey C, Faundez A. Sagittal balance of the spine. Eur Spine J, 2019;28(9), 1889-905. https://doi.org/10.1007/s00586-019-06083-1
14. Alijani B, Rasoulian J. The Sagittal Balance of the Cervical Spine: Radiographic Analysis of Interdependence between the Occipitocervical and Spinopelvic Alignment. Asian Spine J, 2020;14(3), 287-97. https://doi.org/10.31616/asj.2019.0165
15. Pal GP, Sherk HH. The vertical stability of the cervical spine. Spine (Phila Pa 1976), 1988;13(5), 447-9. https://doi.org/10.1097/00007632-198805000-00001
16. Scheer JK, Tang JA, Smith JS, Acosta FL, Protopsaltis TS, Blondel B, et al. Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine, 2013;19(2), 141-59. https://doi.org/10.3171/2013.4.Spine12838
17. Xing R, Liu W, Li X, Jiang L, Yishakea M, Dong J. Characteristics of cervical sagittal parameters in healthy cervical spine adults and patients with cervical disc degeneration. BMC Musculoskelet Disord, 2018;19(1), 37. https://doi.org/10.1186/s12891-018-1951-8
18. Lee SH, Hyun SJ, Jain A. Cervical Sagittal Alignment: Literature Review and Future Directions. Neurospine, 2020;17(3), 478-96. https://doi.org/10.14245/ns.2040392.196
19. Oh BH, Kim JY, Lee JB, Kim IS, Hong JT, Sung JH, et al. Analysis of sagittal parameters for easier and more accurate determination of cervical spine alignment. Medicine (Baltimore), 2023;102(41), e35511. https://doi.org/10.1097/md.0000000000035511
20. Zhu Y, Zhang X, Fan Y, Zhou Z, Gu G, Wang C, et al. Sagittal alignment of the cervical spine: radiographic analysis of 111 asymptomatic adolescents, a retrospective observational study. BMC Musculoskelet Disord 2022;23(1), 840. https://doi.org/10.1186/s12891-022-05792-x
21. Shen YW, Yang Y, Hong Y, Ding C, Rong X, Meng Y, et al. Association of Craniocervical Sagittal Alignment With the Outcomes of Cervical Disc Replacement. Global Spine J, 2024;14(3), 846-55. https://doi.org/10.1177/21925682221124531
22. Lee HJ, Oh BH, Kim JY, Kim JH, Kim IS, Hong JT, et al. Analysis of Parameters That Can Predict the Cervical Sagittal Vertical Axis in Cervical Fusion Surgery. World Neurosurg, 2022;164, e1071-77. https://doi.org/10.1016/j.wneu.2022.05.099
23. Lin T, Wang J, Chen G, Liu W. Predictive Effect of Cervical Sagittal Parameters on Conservative Treatment of Single-Segment Cervical Spondylotic Radiculopathy. World Neurosurg, 2020;134, e1028-36. https://doi.org/10.1016/j.wneu.2019.11.081
24. Protopsaltis TS, Ramchandran S, Tishelman JC, Smith JS, Neuman BJ, Jr GMM, et al. The Importance of C2 Slope, a Singular Marker of Cervical Deformity, Correlates With Patient-reported Outcomes. Spine (Phila Pa 1976), 2020;45(3), 184-92. https://doi.org/10.1097/brs.0000000000003214
25. Caffard T, Arzani A, Verna B, Tripathi V, Chiapparelli E, Medina SJ, et al. Association between Cervical Sagittal Alignment and Subaxial Paraspinal Muscle Parameters. Spine (Phila Pa 1976), 2023;49(9),621-29. https://doi.org/10.1097/brs.0000000000004897
26. Manoharan SR, Joshi D, Owen M, Theiss SM, Deinlein D. Relationship of Cervical Sagittal Vertical Alignment After Sagittal Balance Correction in Adult Spinal Deformity: A Retrospective Radiographic Study. Int J Spine Surg, 2018;12(2), 269-75. https://doi.org/10.14444/5033
27. Lee CK, Shin DA, Yi S, Kim KN, Shin HC, Yoon DH, et al. Correlation between cervical spine sagittal alignment and clinical outcome after cervical laminoplasty for ossification of the posterior longitudinal ligament. J Neurosurg Spine, 2016;24(1), 100-7. https://doi.org/10.3171/2015.4.Spine141004
28. Li J, Zhang D, Shen Y. Impact of cervical sagittal parameters on axial neck pain in patients with cervical kyphosis. J Orthop Surg Res, 2020;15(1), 434. https://doi.org/10.1186/s13018-020-01909-x
29. Zhu W, Sha S, Liu Z, Li Y, Xu L, Zhang W, et al. Influence of the Occipital Orientation on Cervical Sagittal Alignment: A Prospective Radiographic Study on 335 Normal Subjects. Sci Rep, 2018;8(1), 15336. https://doi.org/10.1038/s41598-018-33287-0
30. Tang Y, Zhao W, Liu X, Yu M. Normative values of cervical sagittal alignment according to global spine balance: based on 126 asymptomatic Chinese young adults. Eur Spine J, 2021;30(9), 2427-33. https://doi.org/10.1007/s00586-021-06756-w
31. Park JH, Cho CB, Song JH, Kim SW, Ha Y, Oh JK. T1 Slope and Cervical Sagittal Alignment on Cervical CT Radiographs of Asymptomatic Persons. J Korean Neurosurg Soc, 2013;53(6), 356-9. https://doi.org/10.3340/jkns.2013.53.6.356
32. Yuseli S, Yaltirik CK. Cervical Spinal Alignment Parameters. Turkishspine 2019;30(3), 181-6.
33. Lee HJ, Jeon DG, Park JH. Correlation between kinematic sagittal parameters of the cervical lordosis or head posture and disc degeneration in patients with posterior neck pain. Open Med (Wars), 2021;16(1), 161-8. https://doi.org/10.1515/med-2021-0219
34. Charles YP, Prost S, Pesenti S, Ilharreborde B, Bauduin E, Laouissat F, et al. Variation of cervical sagittal alignment parameters according to gender, pelvic incidence and age. Eur Spine J, 2022;31(5), 1228-40. https://doi.org/10.1007/s00586-021-07102-w
35. Wróblewski R, Gasik R. Parameters of sagittal balance in view of studies on patients suffering from rheumatoid arthritis with cervical spine instability. Reumatologia, 2021;59(6), 411-19. https://doi.org/10.5114/reum.2021.112352

36. Özer AF, Ateş Ö, Çerezci Ö, Hekimoğlu M, Aydın AL, Öktenoğlu T, et al. Changes in cervical sagittal alignment and the effects on cervical parameters in patients with cervical spondylotic myelopathy after laminoplasty. J Craniovertebr Junction Spine, 2021;12(2), 183-90. https://doi.org/10.4103/jcvjs.jcvjs_213_20
37. Martini ML, Neifert SN, Chapman EK, Mroz TE, Rasouli JJ. Cervical Spine Alignment in the Sagittal Axis: A Review of the Best Validated Measures in Clinical Practice. Global Spine J, 2021;11(8), 1307-12. https://doi.org/10.1177/2192568220972076
38. Azimi P, Yazdanian T, Benzel EC, Hai Y, Montazeri A. Sagittal balance of the cervical spine: a systematic review and meta-analysis. Eur Spine J, 2021;30(6), 1411-39. https://doi.org/10.1007/s00586-021-06825-0
39. Teo AQA, Thomas AC, Hey HWD. Sagittal alignment of the cervical spine: do we know enough for successful surgery? J Spine Surg, 2020;6(1), 124-35. https://doi.org/10.21037/jss.2019.11.18
40. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery, 2015;76(1), S14-21. https://doi.org/10.1227/01.neu.0000462074.66077.2b
41. Horng MH, Kuok CP, Fu MJ, Lin CJ, Sun YN. Cobb Angle Measurement of Spine from X-Ray Images Using Convolutional Neural Network. Comput Math Methods Med, 2019;2019, 6357171. https://doi.org/10.1155/2019/6357171
42. Patwardhan AG, Khayatzadeh S, Havey RM, Voronov LI, Smith ZA, Kalmanson O, et al. Cervical sagittal balance: a biomechanical perspective can help clinical practice. Eur Spine J, 2018;27(1), 25-38. https://doi.org/10.1007/s00586-017-5367
43. Naderi S, Ozgen S, Pamir MN, Ozek MM, Erzen C. Cervical spondylotic myelopathy: surgical results and factors affecting prognosis. Neurosurgery, 1998;43(1), 43-9. https://doi.org/10.1097/00006123-199807000-00028
44. Chen Y, Luo J, Pan Z, Yu L, Pang L, Zhong J, et al. The change of cervical spine alignment along with aging in asymptomatic population: a preliminary analysis. Eur Spine J, 2017;26(9), 2363-71. https://doi.org/10.1007/s00586-017-5209-1
45. Cheng J, Liu P, Sun D, Ma Z, Liu J, Wang Z, et al. Correlation of cervical and thoracic inlet sagittal parameters by MRI and radiography in patients with cervical spondylosis. Medicine (Baltimore), 2019;98(7), e14393. https://doi.org/10.1097/md.0000000000014393
46. Protopsaltis T, Terran J, Soroceanu A, Moses MJ, Bronsard N, Smith J, et al. T1 Slope Minus Cervical Lordosis (TS-CL), the Cervical Answer to PI-LL, Defines Cervical Sagittal Deformity in Patients Undergoing Thoracolumbar Osteotomy. Int J Spine Surg, 2018;12(3), 362-70. https://doi.org/10.14444/5042
47. Sun J, Zhao HW, Wang JJ, Xun L, Fu NX, Huang H. Diagnostic Value of T1 Slope in Degenerative Cervical Spondylotic Myelopathy. Med Sci Monit, 2018;24, 791-6. https://doi.org/10.12659/msm.906417
48. Chen J, Wang J, Wei X, Guan H, Wang B, Xu H, et al. The importance of preoperative T1 slope for determining proper postoperative C2-7 Cobb's angle in patients undergoing cervical reconstruction. J Orthop Surg Res, 2020;15(1), 507. https://doi.org/10.1186/s13018-020-02016-7
49. Ijima Y, Furuya T, Ota M, Maki S, Saito J, Kitamura M, et al. The K-line in the cervical ossification of the posterior longitudinal ligament is different on plain radiographs and CT images. J Spine Surg, 2018;4(2), 403-7. https://doi.org/10.21037/jss.2018.05.23
50. Xing R, Zhou G, Chen Q, Liang Y, Dong J. MRI to measure cervical sagittal parameters: a comparison with plain radiographs. Arch Orthop Trauma Surg, 2017;137(4), 451-5. https://doi.org/10.1007/s00402-017-2639-5