Research Article

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Parameters of sagittal alignment of lumbar spine

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Abstract

Sagittal alignment of lumbar spine (SALS) is the state of spine in sagittal plane. The spine is a single organ with multiple segments of varying structure and function. These segments are interrelated and can be the cause and effect of malfunction of the other. In addition, there is a significant role of pelvis and cranium in maintaining the global sagittal balance.

The lumbar spine plays a vital role in maintaining global sagittal balance because of several factors. Lumbar lordosis (LL) is one of them which helps to distribute body weight evenly to maintain an upright position. In other words, by virtue of LL, human beings can stand upright and walk with perfect balance. LL is basically a compensatory posture and any change in it beyond the normal limit needs further compensation by other parts of the spine and pelvis in order to restore balance. This compensation occurs at the cost of excessive stress in those other parts. Ultimately it can affect overall spinal alignment leading to loss of sagittal balance which in turn results in series of clinical manifestations like chronic back pain and difficulty in walking, bending and standing.

There are various parameters which help to define a perfect SALS. Spinal surgeons should have a good understanding of these parameters not only for the proper evaluation of any spinal problem but also for the appropriate planning of spinal surgery.

Key words: lumbar spine, parameters, pelvis, sagittal alignment

Introduction

Sagittal alignment of lumbar spine (SALS) is the state of spine in sagittal plane that involves balance between spine, pelvis and cranium. The spine is a single organ from cervical to sacral segments and, in addition, the cranium and pelvis act like accessary functional units of spine. To achieve and maintain the perfect sagittal alignment, which is called sagittal balance (SB), there must be a well-controlled relationship and equilibrium between cervical lordosis, thoracic kyphosis and lumbar lordosis in addition to relative position of cranium and pelvis so that a human body can be in upright position maintaining its balance in any position and in motion.[1, 2] By maintaining SALS paraspinal muscles have to contract minimally and thus do not get fatigued. If SALS is lost the muscles have to work harder and spend more energy and easily get fatigued.[1-3] SALS is the most important factor for maintaining an upright position of the body which is affected by numerous factors namely spinal degeneration, musculoskeletal pathologies of spine, normal anatomy and pathology of pelvis etc. There are various parameters which help to define and determine SALS in a human being. These parameters are altered due to the spinal pathology leading to development of symptoms. Therefore, surgical treatment should aim to restore these parameters in addition to adequate decompression of the neural elements.[3-6]

While in upright position, may it be at rest or motion, the body's center-of-mass is centered at center of cranial mass and hip axis (centers of femoral heads) and lower extremities. Any condition that can change body's center-of-mass can lead to sagittal imbalance of spine and thus whole body. Murata et al showed that SALS is maintained by the change in various spinal sagittal parameters according to the position of body.[7] Trauma, vertebral compression fracture, degenerative disc disease (DDD), spine pathologies, iatrogenic factors like previous surgical fusion etc. can lead to loss of SALS (sagittal imbalance) and increased or decreased lordosis or kyphosis. SB depends on many factors namely angle of pelvis and sacrum (pelvic incidence), lumbar lordosis, thoracic kyphosis, cervical lordosis which can be defined with the help of different parameters.[7-13] The Pelvis is an important contributor to the maintenance of SALS. When spine is flexible as in younger people, kyphosis or lordosis is compensated by the upper and lower segments of the spine by their counter movement in the opposite direction. But when the spine gets more and more rigid due to age or any other factors the only remaining compensatory mechanism is by the

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movement of the pelvis, anteriorly or posteriorly. Therefore, pelvic parameters like pelvic tilt, sacral slope etc play equally vital roles in the evaluation of SALS.[8, 11, 14-18]

Flat back syndrome, also called fixed sagittal imbalance is an example of loss of SALS in which lumbar spine loses its normal lordosis leading to loss of thoracic kyphosis and finally straightening of the whole spine and spine appears straight. This leads to additional stress on back muscles and thus chronic back pain, inability to stand upright for longer periods and abnormal posture leading to additional stress on the spine.[2, 3, 8, 9, 19-23]

This article doesn't include anything about coronal balance of lumbar spine, which means scoliosis, which is a different spinal entity. In routine clinical practice sagittal balance is more important in terms of function and clinical symptoms related to spine. This article doesn't include details about surgical procedures either. The objective of this article is to define various parameters of SALS and to facilitate young spinal surgeons understanding the relationship between them.

Parameters of SALS

C7 plumb line and sagittal vertical axis (SVA)

A line drawn vertically downward from the center of C7 in a lateral view (LV) Xray of whole spine is called C7 plumb line (Figure 1,Line AB).

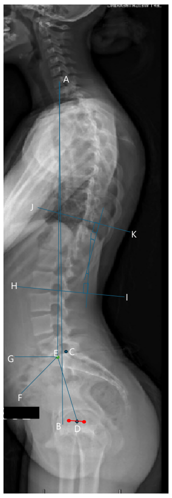

Figure 1: Xray of whole spine and pelvis showing different parameters, A=center point of C7, AB=plumb line from the center of C7, C=superoposterior point of sarum, D=hip axis, E=center point of superior sacral plate, EF=line on the surface of S1 endplate, EG=horizontal line, red dots=centers of two femoral head, D=hip axis

SVA is the measurement of the perpendicular distance between C7 plumb line and posterosuperior point of S1 endplate. It measures how far the C7 plumb line deviates front or back relative to the sacrum and indicates overall sagittal balance. It is the most common measure of global sagittal alignment of spine. In general, the central point of C7 vertebral body should coincide with the posterosuperior point of S1 vertically and it is said to be a neutral balance. Therefore, normal SVA should be </=5cm This is considered to be a well-tolerable range for a health-related quality of life. As people get older, they tend to lean forward to tolerate a slightly wider range of positive SVA. If the C7 plumb line is forward >5cm then the condition is called positive sagittal imbalance, and if backward is called negative imbalance of the spine. A SVA that is significantly greater, more than 5 centimeters, indicates potential sagittal imbalance in the spine. Previous studies have shown that even mildly positive sagittal balance is harmful, and the severity of symptoms increases in linear fashion with progressive sagittal imbalance.[21, 24, 25] Spinal problems like central canal stenosis can lead to sagittal imbalance especially positive SVA and can be corrected by appropriate surgical procedures.[4, 9, 12]

Lumbar lordosis (LL)

Lordosis is a normal forward curvature of the lumbar spine. When there is excessive curvature of the lumbar spine anteriorly, ie more convexity anteriorly, the condition is called lumbar hyperlordosis. Even though the curvature is a normal part of the lumbar spine and thus the whole spine, it can cause problems if excessive. It occurs due to relatively weaker abdominal muscles in front and strong contraction of paraspinal muscles and hamstrings on the back. LL is basically a compensatory mechanism for other abnormalities like sacral slope, thoracic kyphosis etc. When there is lumbar hyperlordosis, the buttocks are pulled up, hips move forward, pelvis tilt anteriorly and abdomen protrude. This leads to low back pain and forward leaning posture. This further leads to more kyphosis of the thoracic spine and loss of normal lordosis of cervical spine as a compensatory mechanism which in turn creates further abnormal spinal curvatures, more spinal stress and degeneration and finally global sagittal imbalance of spine and spinal instability.

LL is measured using the cobb angle method between L1 and S1 in a LV Xray of lumbar spine (LS). The angle made by the intersecting lines (Figure 2, Lines GH and KL) that are perpendicular to the lines of superior endplate of L1 (Figure 2, Line IJ) and endplate of S1 (Figure 2, Line AB)

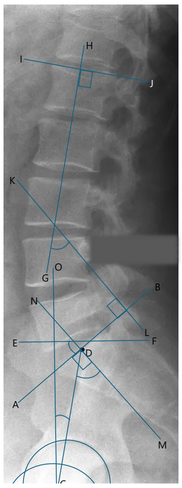

Figure 2: Xray lateral view of lumbosacral spine including pelvis and hip joints showing angles of various parameters, AB=line of S1 endplate, C=hip axis (center of femoral heads), D=center of S1 endplate, DC=line joining center of S1 and hip axis, EF=horizontal line, GH=perpendicular line to IJ, IJ=superior endplate of L1, KL=perpendicular line to AB, MN=perpendicular line to AB at its center point, CO=vertical line, blue semicircles=two femoral heads

represents LL. Normally LL has a wide range of angle and roughly it is between 40° to 60°. Lower segments of the lumbar spine play a major role in the development of LL. Of total LL, more than two third, about 75%, occurs at L4-S1 and 50% occurs at L5-S1.(26) Similarly, Pesenti et al found 62% of total lordosis being contributed by L4-S1 segment while only 32% by L1-4 segment.(16) A lordotic angle of less than 23 degrees defines hypolordosis and more than 68 degrees, hyperlordosis. (27)

Pelvic incidence (PI)

Pelvic incidence is the parameter used to understand the relationship between spine and pelvis. More specifically, it indicates the relationship between sacrum and femoral heads and is key to understanding and determining SALS. It is also called the angle of sacrum in relation to femoral heads.

It differs among individuals due to different pelvic anatomy and shape and is considered a morphological feature not affected by posture and external forces. In fact, PI is regarded as a relatively fixed anatomical angle and remains relatively unchanged in normal anatomy due to relatively immobile sacroiliac joint while other parameters like "pelvic tilt" and "sacral slope" change depending on posture and position. Even though PI doesn't change significantly it appears increased or decreased depending on posture. There can be small variations in PI when changing pelvic position between standing and sitting postures.[15, 28, 29] These changes are usually considered minimal and not clinically significant. However, PI changes in various stages of life. PI increases with age when a child starts walking.[22, 23, 30, 31] In adolescence, PI increases in the process of further development of walking till there is bone maturity. When a person gets older there is further increase in PI to accommodate with the spinal pathology. PI also changes with spinal procedures like spinal fusion. PI also differs between sexes and among different races.

It is calculated by measuring, in the LV Xray of LS and pelvis, the angle between the line perpendicular to S1 endplate (Figure 2, Line MN) at its midpoint and the one joining midpoint of S1 endplate to the hip axis (center of femoral heads, taken as a center point between the centers of two femoral heads) (Figure 2, Line DC). It is also called pelvisacral angle. Its normal value is about 50°-55°. It is often used along with LL. The relationship of these two parameters should be well maintained in order to maintain the SALS. Sagittal imbalance, if there is, is corrected by the changes in these parameters.

High PI occurs when there is more forward positioning of hip joints (femoral heads) relative to the sacrum putting increased stress on the lumbar spine, disc spaces and hip joints. In other words, high PI indicates that the hip joints are positioned more anteriorly leading to higher LL to maintain SALS which in turn potentially increases risk for spondylolisthesis, facet joint degeneration and DDD due to altered biomechanics of spine. It eventually leads to chronic LBP and instability issues. It also indirectly leads to forward posture as a compensatory mechanism. Studies have shown that high PI can be associated with higher prevalence of degenerative lumbar spondylolisthesis.[25, 30]

Low PI occurs when there is more backward positioning of hip joints relative to the sacrum. It signifies a smaller angle between the sacrum and the pelvic inlet. It is associated with decreased natural lumbar lordosis. Low PI means a reduced ability to compensate for the sagittal balance which could lead to a more posterior (backward) posture depending on other factors like pelvic tilt and sacral slope.

Normally LL and PI are almost equal with a mismatch of only about 10°. Pesenti et al found that PI had more influence on proximal LL (L1-L4) rather than distal (L4-S1).[16] Sometimes the mismatch can exceed more than 10° due to loss of LL as a result of degeneration or previous spinal surgery or any other spinal pathology.[12, 32] Excessive mismatches, > 10° can lead to adjacent spine disease (ASD) after spinal fusion.

Pelvic tilt (PT)

Pelvic tilt is another vital parameter of measuring SALS. It indicates the position of pelvis in relation to femoral bones, lower limbs and rest of the body. It denotes the positional orientation of the pelvis, which varies according to position in relation to a transverse axis passing through the two femoral heads. PT is measured by the angle made by a line, in a LV Xray of LS including pelvis, joining the midpoint of S1 endplate and hip axis (Figure 2, Line CD) and the one that is vertically extended upward from the hip axis (Figure 2, Line CO). Normally it is about 20°-25°. However, it can vary according to posture of spine and position of patient. When the pelvis rotates backward (retroversion), PT measurement increases, when the pelvis rotates forward (anteversion), PT measurement decreases. There is a triangular relationship between LL, PI and PT. Abnormal PT can be anterior (APT), pelvic anteversion, or posterior (PPT), pelvic retroversion. APT i.e. forward tilting of the pelvis causes hip joints and sacrum to move backward relative to pelvis leading to protrusion of buttocks. This causes an unusually large degree of LL, a highly sloped sacrum, and a relatively small PI due to relative position of pelvis with spine.[11] This is relatively a more common type of pelvic tilt. However, prevalence of APT or PPT depends on the type of population. Old people who have lost their LL tend to develop PPT. PPT occurs when the pelvis is tilted backward and causes hip joints and sacrum to move forward relative to the pelvis. Abnormal PT can lead to chronic low back pain (LBP).[3]

Sacral slope (SS)

The sacral plateau acts as a base of the whole spine and thus plays a vital role in spinal alignment and stability. Therefore, SS acts like a foundation for LL. PI, PT and SS have a well-balanced relationship with each other. It is measured by the angle made by horizontal line (Figure 2, Line EF) with the line of S1 endplate (Figure 2, Line AB) in a LV Xray of LS. Degree of SS determines the position of lumbar spine. Studies have shown that higher SS can lead to increased movement at L5-S1 and increased contact stress on hip joints and sacroiliac joints.(33) Therefore, high SS results in higher LL. In general PI=PT+SS, therefore if PI is 50°, then SS is 35° and SS is 15°. Ideally, the value for SS should exceed 50% of PI. The minimal value of SS is 0° and in pathology, SS never reaches a negative position, less than 0°, which is the horizontal sacral plate. Both high SS and high PT can lead to high LL. Therefore, high SS and high LL have negative impact on intervertebral disc as well. Studies have shown that spinal integrity and function are well correlated with pelvic morphology.[16,34] Studies have also shown that high SS, PT and LL present a higher risk of developing spondylolisthesis.[30, 34] Therefore, LL, PI, PT and SS all are related and coordinated with each other so that SALS can be well-maintained.

Thoracolumbar kyphosis (TLK)

There is a forward curvature of thoracic spine in a normal state which is called thoracic kyphosis. However, kyphosis can be excessive in certain situations and lead to the symptoms of chronic back pain, stiffness and humpback appearance, forward bending posture and its late complications like breathing problems. Abnormal posture, spinal degeneration and osteoporosis are the most common causes. Usually, thoracolumbar junction is regarded as a segment between T10 and L2 and thus TLK is measured using the Cobb angle method between the superior endplate of T10 and inferior endplate of L2.[35,36] To measure thoracolumbar kyphosis, the vertebral bodies of T10 and L2 on a LV Xray are identified, then lines along the superior endplate of T10 (Figure 1, Line JK) and the inferior endplate of L2 (Figure 1, Line HI) are drawn, the angle made by the lines perpendicular to above mentioned lines represents the degree of thoracolumbar kyphosis. A TLK of more than 20◦ is considered to be pathological.[37]

Spinopelvic angle (SPA)

It is the angle between the long axis of spine and the pelvis as its name suggests. More specifically it's the angle between the center of C7 vertebra and hip axis (center of femoral head). It is measured by drawing a line from the center of C7, in a LV of whole spine Xray including pelvis and femoral heads, to the center of the S1 endplate (Figure 1, Line AE). Another line is drawn from the center of the superior sacral plate to the hip axis (Figure 1, Line DE). The angle thus made by these two lines re measured. SPA defines and estimates the posture and position of a human being in a standing position and measures the global spinal balance.(11, 14) Patient in the position with his/her hip flexion has high SPA and thus it is affected by the motion and position of spine and pelvis.

Spino-sacral angle (SSA)

It is the angle between the spine and sacrum. More specifically it is the measurement of the angle between theC7 vertebra and superior sacral plate. It is used to evaluate the degree of kyphosis of the spine as a whole i.e. global kyphosis. It is measured by drawing a line from the center of C7, in a LV of whole spine Xray including pelvis and femoral heads, to the center of the superior sacral plate (Figure 1, Line AE). Another line is drawn as a straight line on the surface of S1 endplate from its center (Figure 1, Line EF). The angle between these two lines is SSA. Studies have shown that average SSA is about 130° and it usually doesn't change in a healthy person remaining proportional to SS and LL. The more decrease in SSA the more the increase in severity of kyphosis suggesting lower SSA indicates more kyphosis. In case of kyphosis or loss of LL, SSA decreases.[11, 14, 38, 39]

Conclusion

The whole spine from cervical to sacral segment is a single organ from its function perspective. In addition, the pelvis plays a vital role in maintaining SALS. SALS has an important impact not only on segmental motion but also on degenerative pathology and health-related quality of life. Various spinal pathologies like DDD, spondylolisthesis, spinal canal stenosis etc. can lead to spinal sagittal imbalance which can further aggravate the symptoms. Furthermore, sagittal imbalance can lead to adjacent segment disease, failure of hard wares placed in the previous procedure and poor outcome of surgical intervention. Therefore, while planning the procedure the concept of SALS has to be kept in mind and its correction should be aimed in addition to decompression of the neuronal structures.

References

1. Bao T, Wang C, Wang Y, Wang T, Zhang Q, Gao F, et al. Relationship between paravertebral muscle degeneration and spinal-pelvic sagittal parameters in patients with lumbar disc herniation. Sci Rep. 2024;14(1):192. Epub 20240102. doi: 10.1038/s41598-023-50836-4. PubMed PMID: 38168685; PubMed Central PMCID: PMCPMC10762092.
2. Berven S, Wadhwa R. Sagittal Alignment of the Lumbar Spine. Neurosurg Clin N Am. 2018;29(3):331-9. Epub 2018/06/24. doi: 10.1016/j.nec.2018.03.009. PubMed PMID: 29933801.
3. Alqroom R. The Quest of Sagittal Balance Parameters and Clinical Outcome after Short Segment Spinal Fusion. Acta Inform Med. 2018;26(1):57-61. doi: 10.5455/aim.2018.26.57-61. PubMed PMID: 29719316; PubMed Central PMCID: PMCPMC5869282.
4. Elmorsy SEH, Abulnasr HA, Hassan Y, Samra M, Eissa EM. Functional outcome of surgical management of low mid-grade lumbar spondylolisthesis when considering the sagittal balance parameters preoperatively: a prospective study. Chin Neurosurg J. 2022;8(1):35. Epub 20221125. doi: 10.1186/s41016-022-00303-2. PubMed PMID: 36434653; PubMed Central PMCID: PMCPMC9700965.
5. Cho JH, Joo YS, Lim C, Hwang CJ, Lee DH, Lee CS. Effect of one- or two-level posterior lumbar interbody fusion on global sagittal balance. Spine J. 2017;17(12):1794-802. Epub 20170602. doi: 10.1016/j.spinee.2017.05.029. PubMed PMID: 28579287.
6. Chang HS. Effect of Sagittal Spinal Balance on the Outcome of Decompression Surgery for Lumbar Canal Stenosis. World Neurosurg. 2018;119:e200-e8. Epub 20180720. doi: 10.1016/j.wneu.2018.07.104. PubMed PMID: 30036716.
7. Murata K, Endo K, Aihara T, Suzuki H, Matsuoka Y, Nishimura H, et al. The impact of sagittal imbalance on walking in patients with lumbar spinal canal stenosis. J Orthop Surg (Hong Kong). 2021;29(2):23094990211010522. doi: 10.1177/23094990211010522. PubMed PMID: 33926315.
8. Le Huec JC, Thompson W, Mohsinaly Y, Barrey C, Faundez A. Sagittal balance of the spine. Eur Spine J. 2019;28(9):1889-905. Epub 20190722. doi: 10.1007/s00586-019-06083-1. PubMed PMID: 31332569.
9. Farrokhi MR, Haghnegahdar A, Rezaee H, Sharifi Rad MR. Spinal sagittal balance and spinopelvic parameters in patients with degenerative lumbar spinal stenosis; a comparative study. Clin Neurol Neurosurg. 2016;151:136-41. Epub 20161031. doi: 10.1016/j.clineuro.2016.10.020. PubMed PMID: 27842292.

10. Zárate-Kalfópulos B, Reyes-Tarrago F, Navarro-Aceves LA, García-Ramos CL, Reyes-Sánchez AA, Alpízar-Aguirre A, et al. Characteristics of Spinopelvic Sagittal Alignment in Lumbar Degenerative Disease. World Neurosurg. 2019;126:e417-e21. Epub 20190226. doi: 10.1016/j.wneu.2019.02.067. PubMed PMID: 30822583.
11. Yokoyama K, Kawanishi M, Yamada M, Tanaka H, Ito Y, Kawabata S, et al. Spinopelvic alignment and sagittal balance of asymptomatic adults with 6 lumbar vertebrae. Eur Spine J. 2016;25(11):3583-8. Epub 20151019. doi: 10.1007/s00586-015-4284-4. PubMed PMID: 26482498.
12. Yokoyama K, Ikeda N, Tanaka H, Ito Y, Sugie A, Yamada M, et al. Long-Term Changes in Sagittal Balance After Microsurgical Decompression of Lumbar Spinal Canal Stenosis in Elderly Patients: A Follow-Up Study for 5-Years After Surgery. World Neurosurg. 2023;176:e384-e90. Epub 20230524. doi: 10.1016/j.wneu.2023.05.069. PubMed PMID: 37236312.
13. Xu S, Guo C, Liang Y, Zhu Z, Liu H. Sagittal Parameters of Spine-Pelvis-Hip Joints in Patients with Lumbar Spinal Stenosis. Orthop Surg. 2022;14(11):2854-62. Epub 20220920. doi: 10.1111/os.13467. PubMed PMID: 36125192; PubMed Central PMCID: PMCPMC9627079.
14. Roussouly P, Pinheiro-Franco JL. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J. 2011;20 Suppl 5(Suppl 5):609-18. Epub 20110802. doi: 10.1007/s00586-011-1928-x. PubMed PMID: 21809016; PubMed Central PMCID: PMCPMC3175914.
15. Place HM, Hayes AM, Huebner SB, Hayden AM, Israel H, Brechbuhler JL. Pelvic incidence: a fixed value or can you change it? Spine J. 2017;17(10):1565-9. Epub 20170629. doi: 10.1016/j.spinee.2017.06.037. PubMed PMID: 28669858.
16. Pesenti S, Lafage R, Stein D, Elysee JC, Lenke LG, Schwab FJ, et al. The Amount of Proximal Lumbar Lordosis Is Related to Pelvic Incidence. Clin Orthop Relat Res. 2018;476(8):1603-11. Epub 2018/07/03. doi: 10.1097/corr.0000000000000380. PubMed PMID: 29965893; PubMed Central PMCID: PMCPMC6259763 Related Research® editors and board members are on file with the publication and can be viewed on request.
17. Ouchida J, Nakashima H, Kanemura T, Ito K, Tsushima M, Machino M, et al. Differences in Involvement of Whole-Body Compensatory Alignment for Decompensated Spinopelvic Sagittal Balance. J Clin Med. 2023;12(14). Epub 20230714. doi: 10.3390/jcm12144690. PubMed PMID: 37510804; PubMed Central PMCID: PMCPMC10381014.
18. Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J. 1998;7(2):99-103. Epub 1998/06/18. doi: 10.1007/s005860050038. PubMed PMID: 9629932; PubMed Central PMCID: PMCPMC3611230.
19. Caprariu R, Popa I, Oprea M, Niculescu M, Poenaru D, Birsasteanu F. Reduction of spondylolisthesis and sagittal balance correction by anterior lumbar interbody fusion (ALIF). Int Orthop. 2021;45(4):997-1001. Epub 20210104. doi: 10.1007/s00264-020-04900-7. PubMed PMID: 33394077.
20. Dai GG, Wang F, Liu L, Liao SC, Xia J, Wang Y, et al. [Sagittal Balance Parameters Correlate with Resorption of the Lumbar Disc Extrusion: Results of a Retrospective Study]. Sichuan Da Xue Xue Bao Yi Xue Ban. 2020;51(4):533-9. doi: 10.12182/20200760205. PubMed PMID: 32691563.
21. Gille O, Skalli W, Mathio P, Kouyoumdjian P, Boishardy A, Gajny L, et al. Sagittal Balance Using Position and Orientation of Each Vertebra in an Asymptomatic Population. Spine (Phila Pa 1976). 2022;47(16):E551-e9. Epub 20220714. doi: 10.1097/brs.0000000000004366. PubMed PMID: 35867624.
22. Zhou XY, Zhao J, Li B, Wang ZB, Zhang ZC, Hu W, et al. Assessment of Sagittal Spinopelvic Balance in a Population of Normal Chinese Children. Spine (Phila Pa 1976). 2020;45(13):E787-e91. doi: 10.1097/brs.0000000000003428. PubMed PMID: 32049939.
23. Hills J, Lenke LG, Sardar ZM, Le Huec JC, Bourret S, Hasegawa K, et al. The T4-L1-Hip Axis: Defining a Normal Sagittal Spinal Alignment. Spine (Phila Pa 1976). 2022;47(19):1399-406. Epub 20220715. doi: 10.1097/brs.0000000000004414. PubMed PMID: 35867583.
24. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976). 2005;30(18):2024-9. doi: 10.1097/01.brs.0000179086.30449.96. PubMed PMID: 16166889.
25. Han F, Weishi L, Zhuoran S, Qingwei M, Zhongqiang C. Sagittal plane analysis of the spine and pelvis in degenerative lumbar scoliosis. J Orthop Surg (Hong Kong). 2017;25(1):2309499016684746. doi: 10.1177/2309499016684746. PubMed PMID: 28139188.
26. Bernhardt M, Bridwell KH. Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. Spine (Phila Pa 1976). 1989;14(7):717-21. doi: 10.1097/00007632-198907000-00012. PubMed PMID: 2772721.
27. Fernand R, Fox DE. Evaluation of lumbar lordosis. A prospective and retrospective study. Spine (Phila Pa 1976). 1985;10(9):799-803. Epub 1985/11/01. doi: 10.1097/00007632-198511000-00003. PubMed PMID: 4089653.
28. Mikula AL, Lakomkin N, Pennington Z, Nassr A, Freedman B, Sebastian AS, et al. Lumbar Lordosis Correction With Transforaminal Lumbar Interbody Fusion in Adult Spinal Deformity Patients with Minimum 2-Year Follow-up. World Neurosurg. 2022;167:e295-e302. Epub 2022/08/12. doi: 10.1016/j.wneu.2022.08.003. PubMed PMID: 35953034.
29. Le Huec JC, Aunoble S, Philippe L, Nicolas P. Pelvic parameters: origin and significance. Eur Spine J. 2011;20 Suppl 5(Suppl 5):564-71. Epub 2011/08/11. doi: 10.1007/s00586-011-1940-1. PubMed PMID: 21830079; PubMed Central PMCID: PMCPMC3175921.
30. Labelle H, Roussouly P, Berthonnaud E, Transfeldt E, O'Brien M, Chopin D, et al. Spondylolisthesis, pelvic incidence, and spinopelvic balance: a correlation study. Spine (Phila Pa 1976). 2004;29(18):2049-54. doi: 10.1097/01.brs.0000138279.53439.cc. PubMed PMID: 15371707.
31. Cai H, Omara C, Castelein R, Vleggeert-Lankamp CL. Sagittal balance parameters in achondroplasia. Brain Spine. 2023;3:102670. Epub 20230903. doi: 10.1016/j.bas.2023.102670. PubMed PMID: 38021024; PubMed

Central PMCID: PMCPMC10668104.
32. Celestre PC, Dimar JR, 2nd, Glassman SD. Spinopelvic Parameters: Lumbar Lordosis, Pelvic Incidence, Pelvic Tilt, and Sacral Slope: What Does a Spine Surgeon Need to Know to Plan a Lumbar Deformity Correction? Neurosurg Clin N Am. 2018;29(3):323-9. doi: 10.1016/j.nec.2018.03.003. PubMed PMID: 29933800.
33. Duval-Beaupère G, Schmidt C, Cosson P. A Barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. Ann Biomed Eng. 1992;20(4):451-62. doi: 10.1007/bf02368136. PubMed PMID: 1510296.
34. Kumaran Y, Nishida N, Tripathi S, Mumtaz M, Sakai T, Elgafy H, et al. Effects of Sacral Slope Changes on the Intervertebral Disc and Hip Joint: A Finite Element Analysis. World Neurosurg. 2023;176:e32-e9. Epub 2023/03/20. doi: 10.1016/j.wneu.2023.03.057. PubMed PMID: 36934869.
35. Pan C, Bourghli A, Li Y, Li L, Kuang L, Wang B, et al. Predicting thoracic kyphosis morphology and the thoracolumbar inflection point determined by individual lumbar lordosis in asymptomatic adults. Eur Spine J. 2024;33(5):1830-9. Epub 2023/10/18. doi: 10.1007/s00586-023-07983-z. PubMed PMID: 37851162.
36. Makhni MC, Shillingford JN, Laratta JL, Hyun SJ, Kim YJ. Restoration of Sagittal Balance in Spinal Deformity Surgery. J Korean Neurosurg Soc. 2018;61(2):167-79. Epub 20180228. doi: 10.3340/jkns.2017.0404.013. PubMed PMID: 29526059; PubMed Central PMCID: PMCPMC5853192.
37. Huang T, Zhao Z, Wang L, Zhang C, Zhao R, Xiong C, et al. Rapid measurement of thoracolumbar kyphosis with the integrated inclinometer of a smartphone: a validity and reliability study. Sci Rep. 2022;12(1):8745. Epub 2022/05/25. doi: 10.1038/s41598-022-12690-8. PubMed PMID: 35610284; PubMed Central PMCID: PMCPMC9130239.
38. Okpala F. Measurement of lumbosacral angle in normal radiographs: a retrospective study in southeast Nigeria. Ann Med Health Sci Res. 2014;4(5):757-62. doi: 10.4103/2141-9248.141548. PubMed PMID: 25328789; PubMed Central PMCID: PMCPMC4199170.
39. Savarese LG, Menezes-Reis R, Bonugli GP, Herrero C, Defino HLA, Nogueira-Barbosa MH. Spinopelvic sagittal balance: what does the radiologist need to know? Radiol Bras. 2020;53(3):175-84. doi: 10.1590/0100-3984.2019.0048. PubMed PMID: 32587427; PubMed Central PMCID: PMCPMC7302896.