Sagittal Balance and Cervical Sagittal Balance: A Whole-Body Framework for Reciprocal Alignment, Clinical Outcomes, and Surgical Planning

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Key message

Cervical alignment is not an isolated curve. It is the cranial end-organ of a linked system in which pelvic morphology, lumbar lordosis, thoracic kyphosis, the thoracic inlet, head position, lower-limb compensation, and the requirement for horizontal gaze interact. Contemporary evidence therefore favors phenotype- and age-adjusted targets over universal numeric correction

Evidence reviewed through August 2026

Abstract: ***<u>Background</u>: Sagittal balance describes the economical alignment of the head, spine, pelvis, and lower extremities in standing. Cervical sagittal balance has traditionally been assessed locally, yet the cervical spine continuously adapts to thoracolumbar alignment and horizontal-gaze demands. <u>Purpose</u>: To synthesize the relationship between global and cervical sagittal alignment, summarize clinically useful measurements, and highlight findings published through 2026 that refine outcome prediction and surgical planning. <u>Methods</u>: A narrative review of foundational and recent peer-reviewed literature was performed, prioritizing systematic reviews, multicenter deformity cohorts, normative studies, and contemporary studies of reciprocal change, degenerative cervical myelopathy, age-adjusted targets, and predictive modeling. <u>Results</u>: T1 slope is the principal regional bridge between thoracic and cervical shape; greater T1 slope generally requires greater C2–C7 lordosis to preserve gaze. Positive global malalignment can provoke cervical hyperlordosis, pelvic retroversion, and lower-limb flexion. Thoracolumbar correction often relaxes compensatory cervical lordosis, whereas cervical reconstruction can alter thoracic kyphosis, lumbar lordosis, pelvic tilt, and global axis. Increased C2–C7 sagittal vertical axis, excessive T1 slope–cervical lordosis mismatch, abnormal C2 slope, and impaired horizontal gaze are associated with worse disability in several- but not all- populations. Recent evidence reinforces age- and phenotype-specific proportionality and shows that achieved alignment frequently diverges from surgeon-planned targets. <u>Conclusions</u>: Cervical and global sagittal balance should be interpreted as a coupled, dynamic system. Whole-body standing imaging, assessment of flexibility and compensation, and alignment goals individualized to age, morphology, symptoms, and the driver of deformity are more defensible than rigid pursuit of a single cervical angle.***

Keywords: adult spinal deformity; cervical deformity; cervical sagittal vertical axis; T1 slope; cervical lordosis; reciprocal change; horizontal gaze; whole-body alignment

1. Introduction

Sagittal balance is the three-dimensional body's sagittal-plane strategy for maintaining the head over the pelvis and the center of mass over the feet with acceptable muscular expenditure. The classic thoracolumbar paradigm- pelvic incidence (PI), lumbar lordosis (LL), pelvic tilt (PT), sagittal vertical axis (SVA), and T1 pelvic angle (TPA)- established that malalignment correlates with pain, disability, and mechanical complications. The cervical spine adds a special requirement: preservation of horizontal gaze and a stable visual field. Consequently, a cervical curve that appears "abnormal" in isolation may be an appropriate compensation for a deformity elsewhere, whereas a numerically lordotic neck may remain globally malaligned.

The practical implication is that cervical and thoracolumbar reconstruction cannot be planned as independent operations. Correction of one region changes loading and posture in adjacent mobile segments; these reciprocal changes may improve compensation, unmask deformity, or contribute to junctional failure. The modern question is therefore not simply how much cervical lordosis is normal, but whether the head–neck–trunk relationship is proportional for a particular patient, at a particular age, with a particular pelvic and thoracic morphology.

2. Review Scope and Evidence Approach

This narrative review integrates seminal concepts with studies and reviews available through August 2026. Priority was given to peer-reviewed systematic reviews and meta-analyses, multicenter adult spinal deformity (ASD) and adult cervical deformity (ACD) cohorts, full-body radiographic studies, and disease-specific evidence in degenerative cervical myelopathy (DCM), cervical laminoplasty, fusion, and deformity correction. Because definitions, radiographic positioning, surgical populations, and outcome instruments vary substantially, associations are described without implying causal thresholds when validation is incomplete.

3. Conceptual Model: A Linked Head-to-Feet Chain

Pelvic incidence determines the morphologic demand for lumbar lordosis. Lumbar shape influences thoracic orientation; thoracic kyphosis and the position of T1 set the base upon which the cervical spine balances the head. When lumbar lordosis is lost, patients may recruit pelvic retroversion, thoracic flattening, cervical hyperlordosis, posterior pelvic translation, hip extension, knee flexion, and ankle dorsiflexion. These mechanisms preserve gaze and keep the gravity line within the base of support, but they increase muscular demand and may conceal the magnitude of the primary deformity [1–6].

The T1 slope (T1S) is the key cervicothoracic intermediary. Conceptually analogous to sacral slope for the lumbar spine, a larger T1S requires more subaxial cervical lordosis to keep the head centered; a smaller T1S requires less lordosis and may coexist with a straight or kyphotic C2–C7 contour without clinical deformity. T1S is not fixed: it changes with thoracic kyphosis, trunk inclination, pelvic compensation, and operative correction. The occiput–C2 segment provides an additional reserve for gaze, often changing in the direction opposite to subaxial alignment.

4. Measurement Framework

Reliable interpretation begins with standardized, relaxed standing imaging that includes the skull, femoral heads, and preferably the lower limbs. Forced "stand straight" postures can suppress compensation and reduce ecological validity. Flexion–extension radiographs, supine imaging, CT/MRI, and traction or positioning films help distinguish flexible compensation from fixed structural deformity.

Parameter	Definition / role	Clinical interpretation
C7 SVA	Horizontal offset from C7 plumb line to posterosuperior S1.	Global translation; age-sensitive and posture-sensitive. Positive SVA often drives compensatory cervical lordosis.
PI–LL	Pelvic incidence minus L1–S1 lordosis.	Morphologic mismatch; useful but insufficient alone because lordosis distribution and age matter.
PT	Angle reflecting pelvic retroversion.	Compensation marker; can mask forward trunk translation.
TPA / global tilt	Angular measures incorporating trunk inclination and pelvic retroversion.	Less dependent on radiographic magnification; useful for global deformity severity.
C2–C7 lordosis (CL)	Cobb angle between C2 and C7 endplates (method must be specified).	Shape measure, not a stand-alone balance target; strongly dependent on T1S and upper-cervical compensation.
C2–C7 SVA (cSVA)	Horizontal distance from C2 centroid/plumb line to posterior-superior C7.	Anterior head translation; values around >40 mm commonly define deformity/risk but are not universal treatment thresholds.
T1S–CL	T1 slope minus C2–C7 lordosis.	Proportionality measure. Mismatch roughly >15–20° is frequently used as a modifier; interpretation varies by age and diagnosis.
C2 slope	Angle of the C2 inferior endplate to horizontal.	Integrates T1S–CL and upper-cervical posture; increasingly useful as a compact deformity marker.
CBVA / slope of line of sight	Craniofacial horizontal-gaze measures.	Essential in severe deformity; both downward and excessive upward gaze are disabling.
McGregor slope / cranial tilt	Cranial orientation relative to horizontal or C7.	Quantifies gaze compensation and head posture.
Thoracic inlet angle / neck tilt	Morphologic and positional cervicothoracic measures.	Explain the relationship among T1S, neck tilt, and cranial balance; measurement reproducibility varies.

5. What is "normal" cervical sagittal alignment?

Asymptomatic populations demonstrate wide variation in cervical shape. Lordotic, straight, sigmoid, and locally kyphotic contours may all occur without disability. Ageing generally increases T1S, thoracic kyphosis, cSVA, and compensatory cervical lordosis, but the direction and magnitude differ by sex, ethnicity, pelvic morphology, and radiographic protocol. A 2025 systematic review and meta-analysis of asymptomatic sagittal cervical parameters reinforced the breadth of normative variation and heterogeneity of measurement, arguing against a single normal C2–C7 angle [7].

Proportionality is more informative than raw lordosis. The cervical spine must supply enough curvature for the inclination of its base while the upper cervical spine maintains gaze. T1S–CL, C2 slope, and cSVA therefore capture different aspects of the same task: regional shape, head translation, and cranio-cervical compensation. However, correlations among these measures are not perfect, and thresholds derived from deformity cohorts should not be transplanted automatically to DCM, short-segment fusion, or asymptomatic patients.

6. Correlation between Global and Cervical Balance

6.1 Thoracolumbar deformity drives cervical compensation

Positive global malalignment commonly shifts the trunk and T1 forward. To retain horizontal gaze, patients increase C2–C7 lordosis and may extend the occiput–C2 segment. Smith and colleagues showed that correction of thoracolumbar sagittal malalignment can spontaneously reduce preoperative cervical hyperlordosis [3]. Subsequent studies confirmed that preoperative global SVA, T1S, thoracic kyphosis, planned PT/SVA correction, and the upper instrumented vertebra influence the direction and magnitude of postoperative cervical change [4–6].

The relationship is mediated rather than purely linear. LL affects thoracic kyphosis and trunk inclination; thoracic alignment changes T1S; T1S determines the amount of cervical lordosis required. Pelvic retroversion and knee flexion can reduce apparent SVA while maintaining an energetically expensive posture. Thus, a near-normal C7 SVA does not exclude substantial cervical compensation if PT, lower-limb flexion, or global tilt is abnormal.

Paper ID: SR26902100822 DOI: https://dx.doi.org/10.21275/SR26902100822

6.2 Cervical deformity can drive caudal reciprocal change

The reciprocal pathway also runs caudally. Primary cervical kyphosis with forward gaze may prompt thoracic hypokyphosis, lumbar hyperlordosis, pelvic retroversion, or knee strategies. After cervical realignment, thoracic kyphosis may increase and lumbar/pelvic parameters may relax, particularly when the deformity is flexible and the construct alters the cervicothoracic junction [8–10]. The response depends on deformity driver, apex, rigidity, fusion length, and whether compensation is occurring above or below the pathology.

6.3 Segmental distribution matters

Total C2–C7 lordosis can conceal clinically important morphology. Excessive lordosis concentrated at C6–7 is biomechanically different from a smooth multilevel arc, and upper-cervical extension can mask subaxial kyphosis. Recent normative work has begun to define how T1S influences lordosis distribution and apex location [11]. This supports planning that considers where correction is created, not only the final Cobb angle.

7. Clinical correlations and patient-reported outcomes

The most reproducible clinical signal is anterior head translation. Tang et al. linked increasing cSVA with greater disability after multilevel posterior cervical fusion, helping establish the frequently cited 40-mm cSVA modifier [12]. Later cervical deformity cohorts associated cSVA, T1S–CL, CBVA, and C2 slope with disability and health-related quality of life (HRQoL), while multicenter analyses found that achieving improvement in several modifiers relates to better outcomes [13–15]. Yet effect sizes vary and radiographic improvement does not guarantee symptom improvement.

C2 slope has gained attention because it compresses information about T1S–CL mismatch and upper-cervical compensation into a single angle. In ACD cohorts, larger C2 slope correlates with worse patient-reported outcomes and can help describe residual deformity [16]. It should be regarded as an integrative marker, not a substitute for gaze, neurologic status, dynamic flexibility, or full-body imaging.

In DCM, kyphosis, increased cSVA, and mismatch may be associated with worse baseline neurologic function, axial pain, and reduced recovery after laminoplasty or fusion. However, the latest reviews emphasize inconsistent definitions, retrospective designs, and limited evidence for a correction threshold that independently improves neurologic recovery [17,18]. A 2025 study of subaxial cervical surgery reported comparable pain and functional improvement in kyphotic and non-kyphotic groups irrespective of the magnitude of relordotization, underscoring that decompression, diagnosis, and baseline symptoms can dominate radiographic shape [19].

8. Reciprocal Change after Surgery

Postoperative radiographs represent an evolving state. Some changes occur immediately through positioning and correction; others develop over months as soft tissues adapt, pain decreases, and unfused segments rebalance. Medium-term studies in adolescent and adult deformity populations demonstrate that cervical alignment can continue to evolve and that proximal junctional kyphosis or changes in thoracic kyphosis alter the cervical response [20,21]. Serial assessment is therefore preferable to interpreting a single early postoperative film as the final alignment.

Index intervention	Expected reciprocal response	Planning implication
Thoracolumbar realignment	Reduced compensatory CL and upper-cervical extension when positive global malalignment is corrected; T1S and TK may change.	Avoid treating compensatory cervical hyperlordosis as an independent fixed deformity before global planning.
Cervical kyphosis correction	Potential increase in TK and reduction in caudal compensations; global SVA may shift.	Assess the primary driver and mobile compensation below the construct.
Posterior cervical fusion	Loss of motion reserve; cSVA and T1S–CL may evolve with junctional change.	Model alignment at the cervicothoracic junction and protect reciprocal capacity.
Short-segment ACDF	Local lordosis may increase, but global changes are usually modest and phenotype-dependent.	Do not extrapolate ACD targets to routine degenerative ACDF.
Long fusion to upper thoracic spine	Stronger coupling to TK/T1S; reciprocal cervical change and junctional stress are more likely.	UIV selection and rod contour should be incorporated into whole-spine planning.

9. Latest Findings (2024–2026)

- Normative synthesis: a recent systematic review/meta-analysis confirms broad physiologic variability and exposes major heterogeneity in imaging posture, measurement definitions, and demographic composition. The evidence supports proportional, population-aware interpretation rather than a universal cervical lordosis target [7].
- DCM evidence remains associative: 2024–2025 reviews find that sagittal malalignment is clinically relevant, particularly for posterior procedures and severe kyphosis, but prospective evidence defining when alignment correction independently improves neurologic outcome remains insufficient [17,18].
- Targets are often not achieved: a 2025 multicenter analysis found mean gaps between surgeon-planned and achieved postoperative alignment of approximately 17 mm for cSVA and 10° for C2–C7 Cobb angle, emphasizing the limits of intuition, positioning, construct behavior, and reciprocal change [22].
- Age-specific correction may reduce mechanical failure: 2025 ACD work reported that optimizing age-specific radiographic improvement was associated with markedly

lower distal junctional failure, reinforcing avoidance of indiscriminate overcorrection in older patients [23].

- Predictive modeling is emerging: machine-learning methods have identified nonlinear contributions from PJK, thoracic kyphosis correction, and T1S to cervical imbalance in early-onset scoliosis. These findings are hypothesis-generating and require external validation before routine use [24].
- Regional proportionality is replacing isolated angles: newer ratios and composite measures- such as CL/C7 slope, cSVA/T1S, and C2 slope- attempt to represent the cervical response to its base inclination and global alignment. Early associations are promising, but added value over established measures is not yet settled [16,25,26].
- Lordosis location is becoming a planning variable: 2026 normative research highlights T1S-dependent segmental distribution and apex location, supporting shape-aware rather than Cobb-only reconstruction [11].

10. Practical assessment and surgical planning

A useful workflow is to identify the deformity driver before selecting a numeric target.

- Obtain relaxed, standardized whole-body standing lateral imaging including the skull and femoral heads; include knees/ankles when compensation is suspected.
- Measure global alignment (PI, LL and lordosis distribution, PT, SVA, TPA/global tilt), thoracic shape, T1S, CL, cSVA, T1S–CL, C2 slope, and a gaze parameter.
- Determine whether cervical malalignment is primary, compensatory, or mixed. Compare standing with supine, extension, traction, and MRI/CT alignment to assess flexibility.
- Account for age, frailty, bone quality, neurologic disease, hip/knee pathology, and baseline horizontal-gaze needs. Older adults normally tolerate—or require—more positive alignment than young adults.
- Plan the regional shape and correction distribution, not only the endpoint angle. Consider the apex, upper-cervical reserve, T1 orientation, UIV/LIV, and anticipated reciprocal change.
- Avoid overcorrection. Pursuit of young-adult parameters in an older patient may increase junctional stress, while undercorrection may leave disabling forward translation and muscle fatigue.
- Track PROMs, neurologic function, gaze, and mechanical complications alongside radiographs. A technically improved Cobb angle is not a patient-centered outcome by itself.

11. Controversies and Limitations

First, most evidence is retrospective and enriched for severe deformity treated at high-volume centers. Second, standing posture, arm position, gaze instruction, and inclusion of the lower limbs differ across studies. Third, multiple Cobb conventions and reference landmarks produce noninterchangeable values. Fourth, statistical association between alignment and HRQoL is vulnerable to confounding by pain, myelopathy, frailty, and surgical invasiveness. Fifth, classification modifiers are frequently misinterpreted as operative thresholds. Finally, “normal” is time-dependent: alignment changes with ageing, degeneration, muscle quality, and compensation capacity.

These limitations explain why apparently conflicting studies can both be valid. Alignment may strongly influence outcomes in rigid ACD with gaze impairment, yet contribute little to short-segment decompression outcomes in a patient whose dominant problem is neural compression. The clinical task is to identify when sagittal malalignment is causal, compensatory, incidental, or a risk marker.

12. Future Directions

The field needs prospective, diagnosis-specific studies using standardized relaxed standing and dynamic imaging; age-, sex-, and population-adjusted normative datasets; external validation of proportional and machine-learning models; and trials that distinguish decompression effects from alignment correction. Low-dose biplanar imaging, motion analysis, wearable posture data, muscle MRI, and patient-specific finite-element or musculoskeletal models may allow alignment to be evaluated as a dynamic energy problem rather than a single static radiograph. Clinically meaningful targets should be defined by neurologic recovery, gaze, function, pain, and mechanical durability—not radiographic normalization alone.

13. Conclusion

Global and cervical sagittal balance are inseparable components of a head-to-feet postural system. T1 slope is the principal regional link: thoracolumbar shape and compensation orient T1, while the cervical and cranio-cervical segments respond to maintain gaze. This coupling explains spontaneous reduction of cervical hyperlordosis after thoracolumbar correction and reciprocal caudal changes after cervical reconstruction. Contemporary evidence supports whole-body imaging, identification of the deformity driver, assessment of flexibility and compensation, and age- and phenotype-adjusted planning. Fixed values such as cSVA >40 mm or T1S–CL >15–20° are useful descriptors and risk signals, but they should not be treated as universal correction mandates.

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