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Influence of Preoperative Sagittal Alignment on Functional Recovery in Operated Cases of Cervical Spondylotic Myelopathy

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Abstract

Objective We examine the influence of preoperative cervical sagittal curvature (lordotic or nonlordotic) on the functional recovery of surgically managed cases of cervical spondylotic myelopathy (CSM). The impact of sagittal alignment on the functional improvement of operated CSM cases has not been thoroughly investigated.

Materials and Methods We did retrospective analysis of consecutively operated cases of CSM from March 2019 to April 2021. Patients were grouped into two categories: lordotic curvature (with Cobb angle > 10 degrees) and nonlordotic curvature (including neutral [Cobb angle 0–10 degrees] and kyphotic [Cobb angle < 0 degrees]). Demographic data, and preoperative and postoperative functional outcome scores (modified Japanese Orthopaedic Association [mJOA] and Nurick grade) were analyzed for dependency on preoperative curvature, and correlations between outcomes and sagittal parameters were assessed.

Results In the analysis of 124 cases, 63.1% (78 cases) were lordotic (mean Cobb angle of 23.57 ± 9.1 degrees; 11–50 degrees) and 36.9% (46 cases) were nonlordotic (mean Cobb angle of 0.89 ± 6.5 degrees; –11 to 10 degrees), 32 cases (24.6%) had neutral alignment, and 14 cases (12.3%) had kyphotic alignment. At the final follow-up, the mean change in mJOA score, Nurick grade, and functional recovery rate (mJOArr) were not significantly different between the lordotic and nonlordotic group. In the nonlordotic group, cases with anterior surgery had a significantly better mJOArr than those with posterior surgery ($p = 0.04$), whereas there was similar improvement with either approach in lordotic cases. In the nonlordotic group, patients who gained lordosis (78.1%) had better recovery rates than those who had lost lordosis (21.9%). However, this difference was not statistically significant.

Conclusion We report noninferiority of the functional outcome in the cases with preoperative nonlordotic alignment when compared with those with lordotic alignment. Further, nonlordotic patients who were approached anteriorly fared better than those approached posteriorly. Although increasing sagittal imbalance in nonlordotic spines portend toward higher preoperative disability, gain in lordosis in

Keywords
- ► cervical spondylotic myelopathy
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- ► kyphotic
- ► lordotic
- ► nonlordotic
- ► outcomes
- ► preoperative
- ► sagittal alignment

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such cases may improve results. We recommend further studies with larger non-lordotic subjects to elucidate the impact of sagittal alignment on functional outcome.

Introduction

The role of cervical sagittal (CS) parameters in cervical surgeries is yet to be completely understood. In the last decade, its influence on surgery for cervical spondylotic myelopathy (CSM) has come to the forefront and CS balance has been identified as an important determinant of radiological and clinical outcomes. Studies suggest that CS balance closely relates to patients' health-related quality-of-life (HRQOL) scores just as in the thoracolumbar spine.[1,2]

As far as impact of cervical parameters in CSM is concerned, it has been established that sagittal imbalance (higher CS vertical axis [cSVA]) after surgery portends toward poorer patient-reported outcomes.[3,4] Also, higher preoperative cSVA correlates with higher myelopathy disability.[4–6] Noticeably, the approach used,[7] type of surgery,[8] or the number of levels operated on[9] have not been shown to independently predict surgical outcomes. Several determinants of postoperative neurological recovery such as preoperative myelopathy severity, duration of symptoms, magnetic resonance imaging (MRI), and T2-weighted (T2W) signal intensities (SI) are also well established in the literature.[9–12] However, evidence on the impact of preoperative sagittal curvature on the neurological recovery is still evolving and needs further probing. This study aims to establish the influence of preoperative curvature of the cervical spine (lordotic or nonlordotic) on the neurological recovery and disability of the operated CSM patients at a minimum 1-year follow-up.

Materials and Methods

The study was proceeded after ethical approval of the institutional review board (EC/2/19/2008) for using patient data and informed consent was taken from all the patients before surgical intervention. We performed a retrospective analysis of data of consecutively operated cases of degenerative cervical myelopathy (DCM) from March 2019 to April 2021 at our institute. The inclusion criteria were cases with clinical signs of myelopathy with concordant spinal MRI changes, having age 18 or above with complete set of records, and cervical lateral radiographs having properly visible endplates up to the C7 vertebra. Cases excluded were ossification of the posterior longitudinal ligament (OPLL), tandem stenosis, any previous spine surgery, inflammatory diseases (rheumatoid arthritis or ankylosing spondylitis), infection/neoplasm, trauma, or those who had an incomplete follow-up. ►Fig. 1 depicts the flowchart of the methodology of the study.

Radiographic Assessment

Measurements were done by standard lateral radiographs of cervical spine taken in the neutral position with the upper extremities positioned at the side of the body while maintaining a horizontal gaze. Sagittal parameters measured were (1) C2–C7 lordosis (CL; in degrees); (2) C2–C7 sagittal vertical axis (cSVA; in mm); and (3) C7 slope (C7S; in degrees; ►Fig. 2). Patient demographics were recorded and measurements were done with Surgimap V 2.3.2 (Nemaris Inc., New York City, NY) application by two spine surgeons on two separate occasions and the mean of measurement was further analyzed. These assessors were blinded to the outcomes of the patients. Subjects were grouped into two categories on the basis of the preoperative cervical alignment (►Fig. 3). Lordotic curvature (with Cobb angle >10 degrees) and nonlordotic curvature (including neutral [Cobb angle 0–10 degrees] and kyphotic [Cobb angle < 0 degrees]).[13]

To prevent heterogeneity of patient demographics, it was ensured that both groups were comparable for the number of levels addressed, type of approach used, and preoperative T2W MRI changes (►Table 1). Qualitative MRI changes on T2W sequence included the presence of hyperintensity signal in the cord. Quantitative changes in T2W sagittal MRI were assessed using signal intensity ratio (SI Ratio). It was defined as the ratio between the intensity at the area of the greatest cord SI change and the cerebrospinal fluid (CSF) behind the spinal cord at C2, calculated with 100-pixel circles at both places. The analysis was done using ImageJ software (National Institutes of Health, Bethesda, MD)[5] by

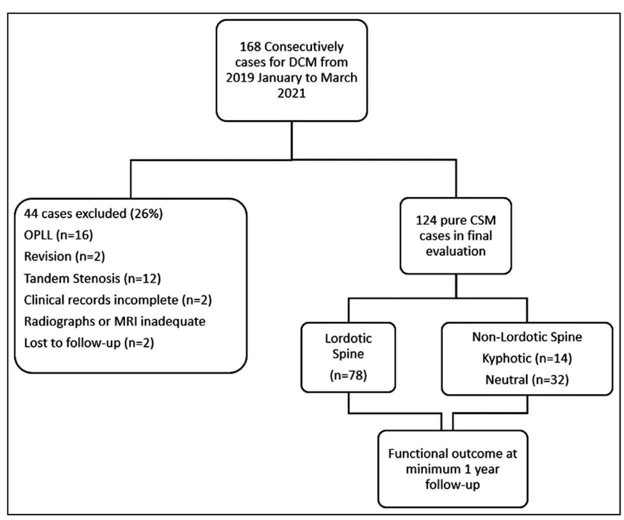

Fig. 1 Flowchart depicting the methodology of the study (CSM, cervical spondylotic myelopathy; DCM, degenerative cervical myelopathy; OPLL, ossification of the posterior longitudinal ligament).

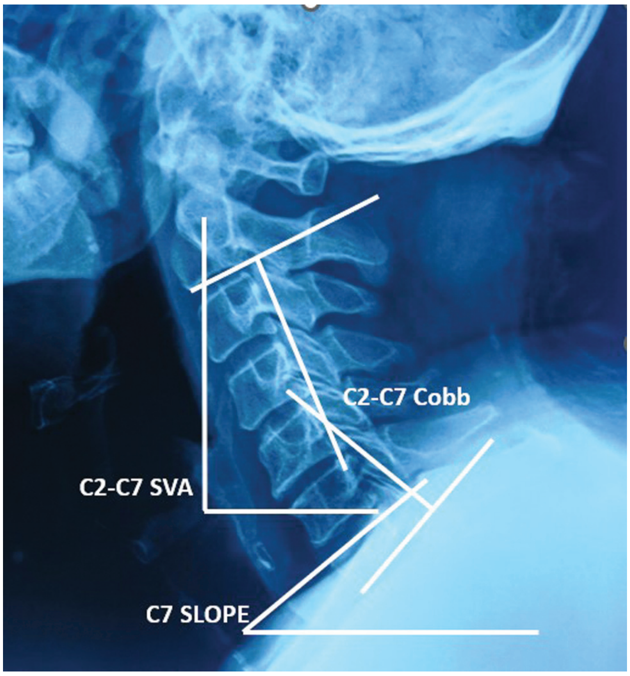

Fig. 2 Sagittal parameters measured were the following: (1) C2–C7 lordosis (CL, in degrees): The Cobb angle between the lower endplates of C2 and C7 vertebral body. " + " denotes lordosis, while "–" denotes kyphotic alignment. (2) C2–C7 sagittal vertical axis (cSVA, in mm): The distance from the posterosuperior corner of C7 to a vertical line from the center of the C2 vertebra. (Anterior shift of the plumbline was assigned " + ", while the posterior shift was assigned "–"). (3) C7 Slope (C7S, in degrees): The angle between the upper endplate of the C7 vertebral body and the horizontal.

two spine surgeons who were blinded to the functional outcomes.

Surgical Procedure

All the patients underwent cervical decompression surgeries, performed by three senior spine surgeons of the orthospine department of the institute. The choice of anterior or posterior surgery was at the discretion of the surgeon. Factors such as number of levels involved, cervical alignment, presence or absence of retrovertebral compression, and patient's surgical capacity were weighed in decision-making. Anterior surgeries included anterior cervical diskectomy and fusion (ACDF), anterior cervical corpectomy and fusion (ACCF), or hybrid surgery, whereas posterior surgeries included cervical laminectomy with or without lateral mass fixation and laminoplasty. In few cases, combined anterior and posterior surgery was done.

Outcome Measurement

Both lordotic curvature (with Cobb angle $>$ 10 degrees) and nonlordotic curvature (including neutral [Cobb angle 0–10 degrees] and kyphotic [Cobb angle $<$ 0 degrees]) were analyzed for various baseline characteristics and checked for comparability. Cases were followed at baseline, postoperatively 1 year, and at last follow-up. Functional outcomes were compared using the change in modified Japanese Orthopaedic Association (mJOA) scale and Nurick grade. The functional recovery rate for the mJOA scale (mJOArr) was calculated using Hirabayashi's method[14]:

$$\frac{\text{Follow-up mJOA} - \text{preoperative mJOA}}{18 - \text{preoperative mJOA}} \times 100\%$$

Nurick grade recovery rate (Nurick RR)[14] was calculated as follows:

$$\frac{\text{Preoperative Nurick grade} - (\text{follow-up Nurick grade})}{\text{Preoperative Nurick grade}} \times 100\%$$

Correlations between the CS parameters and outcomes scores were calculated.

Statistical Analysis

Statistical analysis was performed using IBM SPSS version 23.0 (IBM Corp., Armonk, NY, United States). Continuous

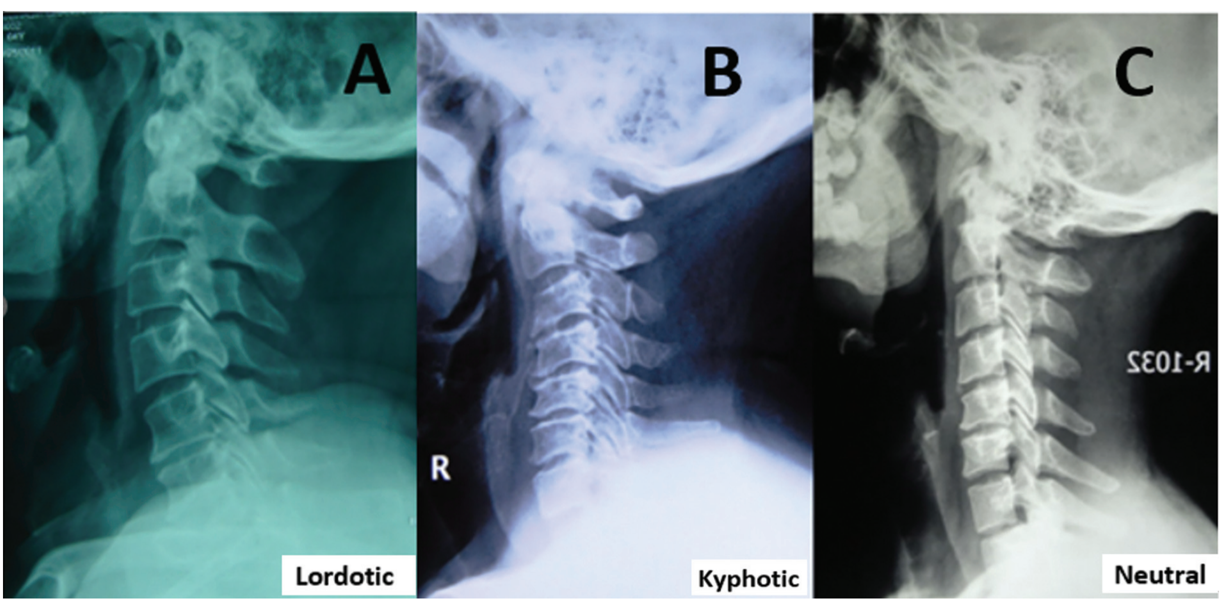

Fig. 3 Cases were divided on the basis of preoperative alignment. (A) Lordotic and nonlordotic curvature. (B) Kyphotic alignment. (C) Neutral alignment.

Table 1 Demographic comparison between lordotic and nonlordotic groups

Parameters	Cobb > 10 ($N=78$) Lordotic	Cobb ≤ 10 ($N=46$) Kyphotic/neutral	*p*-Value
Sex (M:F)	60:10	39:2	0.1
Age (y)	54.1 ± 13.08	51.4 ± 13.37	0.3
ASAPS grade (1:2:3)	41:23:6	27:10:4	0.6
Pre-op severity (mJOA)	11.7 ± 2.18	11.5 ± 2.06	0.6
No. of levels addressed (mean)	2.15 ± 0.93	2.15 ± 0.98	0.9
Approach used (anterior:posterior)	45:32	30:15	0.5
Duration (mo)	5.6 ± 4.4	6.0 ± 4.9	0.6
MRI SI ratio	0.64 ± 0.1	0.66 ± 0.1	0.3
Presence of MRI hyperintensity	88.6%	85.4%	0.7
Mean follow-up (y)	2.5 ± 1.44	2.49 ± 1.51	0.9

Abbreviations: ASAPS, American Society of Anesthesiologists Physical Status; mJOA, modified Japanese Orthopaedic Association; MRI, magnetic resonance imaging; SI, signal intensity.

variables were described using means, standard deviations, and ranges. Quantitative data were first tested for its normality and homogeneity of variance and according to different situations. We used the Shapiro–Wilk test of normality for the continuous variable for linear regression. Categorical variables were summarized using frequencies and percentages. They were tested by Student's *t*-test or Mann–Whitney *U* test, while qualitative data were tested by chi-square test to compare the differences between the lordotic and nonlordotic groups. Spearman's correlational coefficients were calculated to assess associations between CS parameters and outcome measures. The interobserver reliability and intraobserver reproducibility were assessed using intraclass correlation coefficient (ICC) at 95% confidence interval. The level of significance for all analyses was defined as α equal to 0.05.

Results

In our analysis of 124 cases, 63.1% (78 cases) were lordotic and 36.9% (46 cases) were nonlordotic preoperatively. In the nonlordotic group, 24.6% (32 cases) had neutral alignment, while 12.3% (14 cases) had kyphotic alignment. The mean Cobb angle of the lordotic group was 23.57 ± 9.1 degrees (11–50 degrees), whereas the mean Cobb angle of the nonlordotic group was 0.89 ± 6.5 degrees (−11 to 10 degrees). Demographic characteristics of the two groups were not significantly different from each other and the groups were comparable in baseline demographics (►**Table 1**). There was significant increase in mean mJOA score (ΔmJOA = 3.2 ± 0.46; $p < 0.001$) and reduction in Nurick grade (ΔNurick = 1.4 ± 0.32; $p < 0.001$) after surgical intervention. Overall change in the mean sagittal parameters at the last follow-up are summarized in ►**Table 2**. The mean change in mJOA, Nurick grade, and functional recovery rate were not significantly different between the lordotic and nonlordotic groups (►**Table 3**). The surgical approach used in the lordotic group was 57.1% anterior, 41.4% posterior, and 1.4% a combined anterior and posterior approach, whereas in the nonlordotic group, 65.9% were anterior, 31.7% posterior, and 2.4% a combined anterior and posterior surgery. In the nonlordotic group, patients who received anterior surgery had a significantly better mJOArr (60.4 ± 30.2 vs. 41.9 ± 37.1%; $p = 0.04$) than those who were approached posteriorly. Lordotic cases had a similar improvement with either approach. Overall, the mean number of levels operated in the anterior surgery was 1.8 ± 0.81, whereas that in the posterior surgery was 2.80 ± 0.82 ($p < 0.001$).

The lordotic group had a significant loss of mean lordosis (−9.25 ± 1.38 degrees; $p < 0.001$), whereas the nonlordotic group gained lordosis significantly (+4.01 ± 1.39 degrees; $p < 0.003$) at the final follow-up. In the nonlordotic group, patients who gained lordosis (78.1%, $n = 36$) from their

Table 2 Overall change in parameters at the final follow-up

Parameters	Preoperative	Last follow-up	*p* value	ICC
cSVA	18.5 ± 12.73	21.1 ± 12.59	0.001	0.80
C2–C7 Cobb	15.1 ± 13.73	9.9 ± 10.53	< 0.001	0.89
C7 slope	25.1 ± 9.71	19.9 ± 8.15	0.089	0.80
mJOA scale	11.68 ± 2.12	14.86 ± 2.58	< 0.001	–
Nurick grade	3.1 ± 0.97	1.7 ± 1.29	< 0.001	–

Abbreviations: cSVA, cervical sagittal vertical axis; ICC, intraclass correlation coefficient; mJOA, modified Japanese Orthopaedic Association.

Table 3 Comparison of lordosis versus nonlordosis group at the final follow-up

$N=124$	Cobb > 10 ($N=78$) Lordotic	Cobb ≤ 10 ($N=46$) (kyphotic/neutral)	p-Value
Fraction	63.1%	36.9% Kyphotic ($n=14$;12.3%) Neutral ($n=32$; 24.6%)	0.1
Mean Cobb (degrees)	23.57 ± 9.1	0.89 ± 6.5	0.03
ΔCobb (mean ± SD; degrees)	−10.25 ± 5.6	+4.01 ± 2.9	0.006
% of anterior surgery	57.1	67.8	0.6
ΔmJOA	3.21 ± 1.68	3.17 ± 2.37	0.9
ΔNurick	1.50 ± 0.93	1.32 ± 0.92	0.5
Nurick RR (%)	49.19 ± 30.11	48.57 ± 33.89	0.6
mJOArr (%)	52.5 ± 25.84	54.56 ± 33.26	0.9
Final alignment	Lordotic 51.12%	Lordotic 20.5%	–
	Neutral 37.14%	Neutral 62.4%	
	Kyphotic 5.7%	Kyphotic 17.1%	

Abbreviations: mJOA, modified Japanese Orthopaedic Association; mJOArr, functional recovery rate for the mJOA scale; RR, recovery rate; SD, standard deviation.

Table 4 Restoration of lordosis in nonlordotic group and functional outcome

Nonlordotic group	Percentage	Mean ΔCobb (degrees)	mJOArr	Nurick RR
Gain in lordosis ΔCobb (positive)	78.04	6.8	57.07%	53.6%
Loss in lordosis ΔCobb (negative)	21.96	−6.5	42.4%	37.61%
p-Value	–	–	0.08	0.1

Abbreviations: mJOA, modified Japanese Orthopaedic Association; mJOArr, functional recovery rate for the mJOA scale; RR, recovery rate.

baseline alignment had better recovery rates than those who lost lordosis (21.9%, $n=10$). This difference in recovery rates, however, did not meet the statistical significance (mJOArr, $p=0.08$, and Nurick RR, $p=0.1$; ►**Table 4**). Statistically significant correlations between sagittal parameters and the functional scores observed in the two groups are listed in ►**Table 5**.

Discussion

The importance of CS parameters is now increasingly being recognized in planning and assessing the results of patients undergoing surgery for CSM. Conventionally, preoperative cervical alignment dictates the approach to be used for surgery. Posterior decompressive surgeries are preferred in patients with lordotic alignment relying on the cord fallback posteriorly, whereas anterior surgeries are advocated in nonlordotic alignment to restore lordosis.[15] However, the literature seems to be divided with regard to the influence of preoperative alignment on the functional outcome after surgery. Shamji et al[16] reported that patients with preoperative kyphotic alignment showed inferior neurological improvement than those with lordotic curvature. On the other hand, there are studies that show that both lordotic and

Table 5 Correlations between sagittal parameters and functional scores. Increasing sagittal imbalance (higher cSVA) correlates with higher preoperative disability (lower mJOA score) in nonlordotic spine only, while high cSVA postoperatively correlates with poorer functional recovery rates (mJOArr) in both lordotic and nonlordotic groups

Correlations	Nonlordotic	Lordotic
Preoperative cSVA and preop mJOA (disability)	$r=-0.336$, $p=0.01$	$r=0.4$, $p=0.1$
Postoperative cSVA and mJOArr	$r=-0.342$, $p=0.02$	$r=-0.428$, $p<0.001$

Abbreviations: cSVA, cervical sagittal vertical axis; mJOA, modified Japanese Orthopaedic Association; mJOArr, functional recovery rate for the mJOA scale.

nonlordotic alignment had comparable final functional results.[13,17] In this study, we set to determine the influence preoperative alignment had on postoperative functional outcome in 124 cases of pure CSM.

In our analysis, patients with preoperative nonlordotic alignment were not associated with inferior functional results when compared with cases with lordotic alignment. In the nonlordotic cohort, anterior surgery had better functional recovery rates ($p = 0.04$) than those who had posterior surgery. Also, this group had gained mean lordosis of +4.01 degrees at the final follow-up. In all, 78.04% of patients who had gained lordosis showed higher mean recovery rates than 21.6% patients who had lost lordosis (mJOA: 57.07 vs. 42.4%) at the last follow-up. This difference, however, could not reach statistical significance ($p = 0.08$) probably due to a lesser number of kyphotic cases (14 cases, 12.3% overall) in the nonlordotic cohort (►**Table 3**). The authors suggest that realignment toward lordosis plays an important role in the cases which are nonlordotic at baseline. The hypothesis given by Batzdorf and Batzdorf[18] states that gain of lordosis allows spinal cord to fall back from the anteriorly draping compressive forces of the disk osteophytes complex present in a kyphotic spine. Also, both global and segmental kyphoses of cervical spine alter the biomechanics and hasten the degenerative process leading to early arthritic changes with predisposition to adjacent segment degeneration.[19] Direct decompression and improvement in lordosis using anterior approach allows an environment of neurological recovery in such cases as demonstrated in our analysis with the anterior approach surgery faring better than the posterior surgery in the nonlordotic group.

Our results echo with the study of Kaptain et al,[13] who also divided their study cohort on basis of preoperative sagittal alignment into lordotic, straight, and kyphotic curvatures comparing the clinical outcomes of each. They reported that neither preoperative nor postoperative alignment influenced the functional outcome. They went on to suggest that efforts to prevent kyphotic deformity may rather be futile. Similarly, Jain et al[17] showed that the presence of segmental kyphosis preoperatively does not lead to inferior functional results when compared with cases having preoperative lordosis after decompressive surgery. Our results, however, contradict the study by Shamji et al,[16] who reported that patients with preoperative kyphotic alignment were associated with inferior neurological recovery than those who had lordotic alignment at the baseline. They assessed the outcomes by seeing improvements in the mJOA score, Nurick grade, and the 30-second walk test. Noticeably, as compared with this study, they had a higher proportion of kyphotic cases present in their cohort (34 vs. 12%). Also, despite achieving significant correction in sagittal alignment postoperatively in their kyphotic group (mean ΔCobb of $+13 \pm 6$ degrees), they still reported poorer myelopathy recovery as compared with the lordotic group.

The majority of surgical patients with CSM exhibit some neurological improvement following intervention as found in our analysis. Overall, there was significant improvement in the mJOA score ($p < 0.001$) and Nurick grade ($p < 0.001$) at the final follow-up. Preoperative myelopathy severity (preoperative mJOA) correlated with the preoperative cSVA ($p = 0.01$; $r = -0.336$) in the nonlordotic group only and no such correlation was seen in the lordotic alignment group (►**Table 5**). Similar findings have been reported by previous authors in which increasing cSVA correlated with a higher preoperative disability in the kyphotic (nonlordotic) patients and not in the lordotic spine.[5,6] We observed postoperatively the increasing cSVA (sagittal imbalance), that is, a shift of alignment from lordotic to neutral and then finally kyphosis, negatively correlated with the functional outcome, irrespective of whether the preoperative alignment is lordotic or nonlordotic (►**Table 5**; ►**Figs. 4** and **5**). This effect could be explained with increased anterior cord distortion with increasing sagittal imbalance as the neck alignment goes from lordosis to kyphosis. These findings emphasize improving the sagittal alignment as a potential surgical objective in cases of CSM.

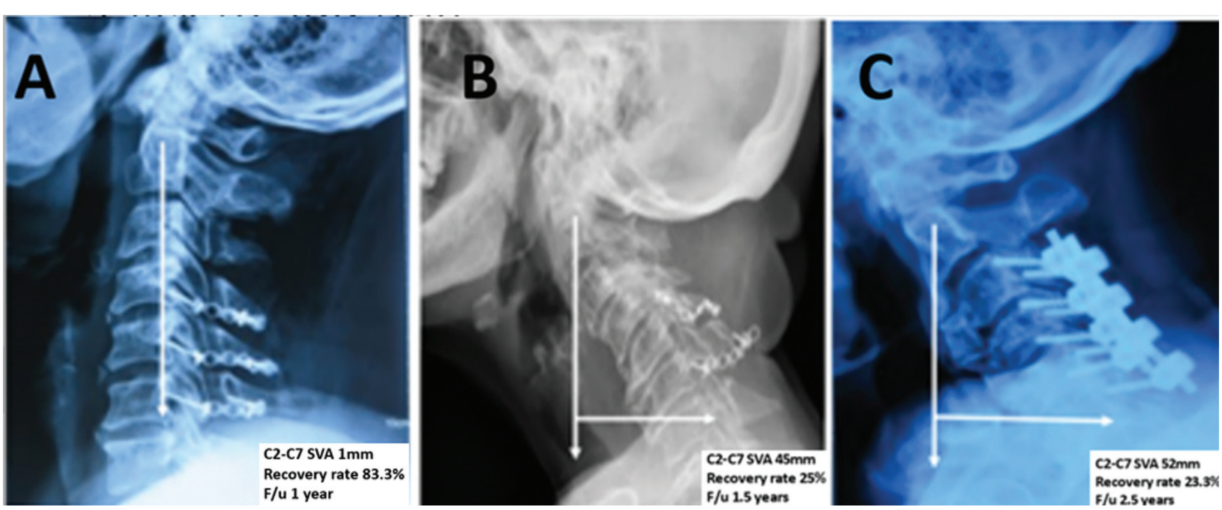

Fig. 4 Postoperative C2–C7 sagittal vertical axis (cSVA) showed statistically significant negative correlation with functional recovery rate in posterior surgeries. Radiographs showing good functional recovery with smaller cSVA as shown in (**A**) a case of laminoplasty than having a larger cSVA as shown in (**B**) a case of laminoplasty and (**C**) a case of posterior laminectomy with lateral mass fixation.

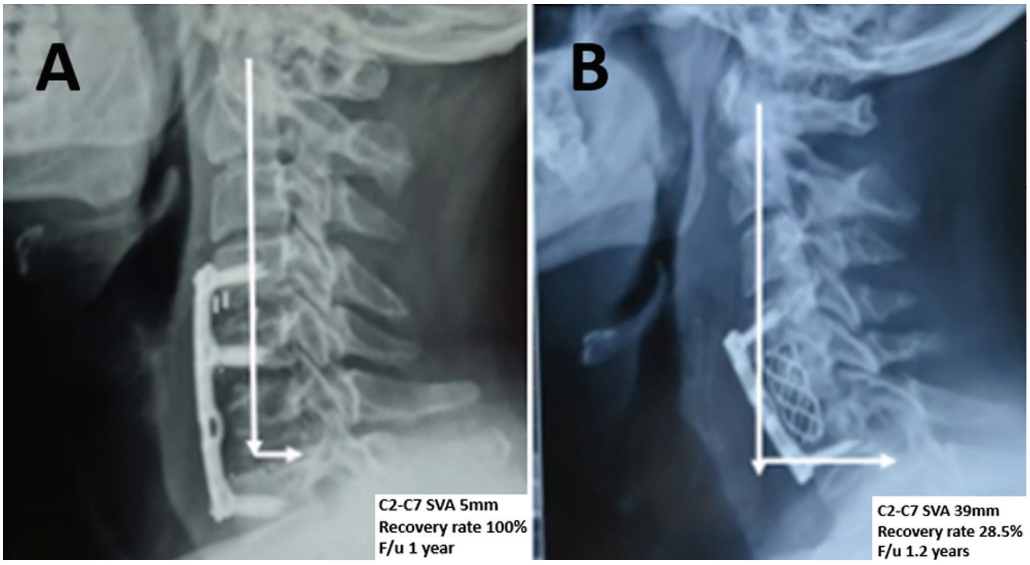

Fig. 5 Postoperative C2–C7 sagittal vertical axis (SVA) showed statistically significant negative correlation with functional recovery rate in anterior surgeries as well. Radiographs showing good functional recovery with smaller cSVA as seen in (**A**) a case of anterior cervical discectomy and fusion than having larger cSVA as shown in (**B**) a case of postoperative anterior cervical corpectomy with mesh cage and plating.

Our analysis shows that the functional results of lordotic and nonlordotic cervical spine were comparable after surgery for CSM provided there was some gain in lordosis in the cases with baseline nonlordotic alignment. The anterior approach faring better than the posterior approach further stresses the importance of improvement in alignment in surgery. However, the magnitude of increase in lordosis, which can be considered sufficient, is a matter of further analysis. Previous reports suggest that the amount of lordotic correction (small or large) does not seem to affect the functional outcome if the final alignment is lordotic.[20] Also, increasing lordosis in preoperatively lordotic spines does not seem to give added functional advantage.[21] At the same time, enormous increase in lordotic alignment may invite complications such as C5 palsy.[22] Thus, it seems defining the optimum correction of alignment and the appraisal of its impact on functional outcome warrant a more robust analysis with larger randomized studies.

We acknowledge various limitations of the study. First, the C0–C2 segment lordosis was not taken into consideration, which has significant contribution to the overall lordosis of the cervical spine. The criterion assigned for neutral curvature (Cobb angle: 0–10 degrees) might constitute to analytical bias. Other limitation would be not analyzing the global alignment parameters including the spinopelvic parameters in a study discussing the impact of the regional cervical parameters on the functional outcome. Also, the retrospective nature of the analysis and a smaller subset of kyphotic patients in the cohort (12.3%) might have reduced the power of the study. We ensured blinding wherever possible to reduce biases in assessment.

Conclusion

Decompression and stabilization seems to be the mainstay of the surgical treatment for CSM. We report the noninferiority of the functional outcome in the cases with preoperative nonlordotic alignment as compared with lordotic alignment of the cervical spine. Sagittal imbalance (high cSVA) postoperatively correlates with poorer functional recovery rates. Also, increasing sagittal imbalance correlates with a higher preoperative disability in the nonlordotic spine, a finding not seen in the lordotic spine. Still realignment towards lordosis in cases with baseline nonlordotic spines have a biomechanical advantage and may lead to improved results. We recommend larger randomized studies to further analyze the true impact of sagittal alignment on outcomes. As a goal for decompressive surgery for CSM, consideration should be given to restoration of cervical lordosis and correction of CS imbalance when present.

Authors' Contribution

Shankar Acharya was responsible for mentoring, conceptualization, and supervision. He was also an operating surgeon. Varun Khanna was responsible for conceptualization, methodology, formal analysis, resources, data curation, and writing—original draft review and editing, the manuscript. He is also the corresponding author. Rupinder Chahal was responsible for the resources, analysis, and proofreading. He was also an operating surgeon. KL Kalra was responsible for data collection and proofreading, and also an operating surgeon.

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Conflict of Interest

None declared.

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