Paraspinal muscle morphometry in cervical spondylotic myelopathy and its implications in clinicoradiological outcomes following central corpectomy

Clinical article


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Object. The objective of this study was to assess the cross-sectional areas (CSAs) of the superficial, deep flexor (DF), and deep extensor (DE) paraspinal muscles in patients with cervical spondylotic myelopathy (CSM), and to evaluate their correlations with functional status and sagittal spinal alignment changes following central corpectomy with fusion and plating.

Methods. In this retrospective study of 67 patients who underwent central corpectomy with fusion and plating for CSM, the CSAs of the paraspinal muscles were calculated on the preoperative T2-weighted axial MR images and computed as ratios with respect to the corresponding vertebral body areas (VBAs) and as flexor/extensor CSA ratios. These ratios were then compared with those in the normative population and analyzed with respect to various clinicoradiological factors, including pain status, Nurick grade, and segmental angle change at follow-up (SACF).

Results. The mean CSA values for all muscle groups and the DF/DE ratio were significantly lower in the study cohort compared with an age- and sex-matched normative study group (p < 0.001). Among various independent variables tested in a multivariate regression analysis, increasing age and female sex significantly predicted a lower total extensor CSA/VBA ratio (p < 0.001), while a longer duration of symptoms significantly predicted a greater total flexor/total extensor CSA ratio (p = 0.02). In patients undergoing single-level corpectomy, graft subsidence had a positive correlation with SACF in all patients (p < 0.05), irrespective of the preoperative segmental angle and curvature, while in patients undergoing 2-level corpectomy, graft subsidence demonstrated such a correlation only in the subgroup with lordotic curvatures (p = 0.02). Among the muscle area ratios, the DF/DE ratio demonstrated a negative correlation with SACF in the subgroup with preoperative straight or kyphotic segmental angles (p = 0.04 in the single corpectomy group, p = 0.01 in the 2-level corpectomy group). There was no correlation of any of the muscle ratios with change in Nurick grade.

Conclusions. Patients with CSM demonstrate significant atrophy in all the flexor and extensor paraspinal muscles, and also suffer a reduction in the protective effect of a strong DF/DE CSA ratio. Worsening of this ratio significantly correlates with greater segmental kyphotic change in some patients. A physiological mechanism based on DF dysfunction is discussed to elucidate these findings that have implications in preventive physiotherapy and rehabilitation of patients with CSM. Considering that the influence of a muscle ratio was significant only in patients with hypolordosis, a subgroup that is known to have facet ligament laxity, it may also be postulated that ligamentous support supersedes the influence of paraspinal muscles on postoperative sagittal alignment in CSM.

(key Words) • cervical spondylotic myelopathy • paraspinal muscles • morphometry • corpectomy • sagittal alignment

Abbreviations used in this paper: CSA = cross-sectional area; CSM = cervical spondylotic myelopathy; DE = deep extensor; DF = deep flexor; ICC = intraclass correlation coefficient; SAC = segmental angle change; SACF = SAC at follow-up; TE = total extensor; TF = total flexor; VBA = vertebral body area.

Alterations in morphometry or strength of cervical paraspinal muscles are known to occur in patients with whiplash injury and chronic neck pain. Deep flexor (DF) muscle dysfunction has proven to be an important biomechanical finding in some of these studies. While it is generally assumed that paraspinal muscles in cervical spondylotic myelopathy (CSM) are atrophic or dysfunctional, there has been no clinicoradiological study so far documenting such a change. The role of paraspinal muscles has also been implicated in influencing sagittal changes after interventions such as central corpectomy. Such a proposition has arisen in light of an inconsistently
proven relationship between graft subsidence and postoperative kyphotic change.\textsuperscript{22,31} We hypothesized that cervical paraspinal muscles are atrophic in the population with CSM and that the ratio of the areas of DFs to that of the deep extensors (DEs) is directly related to segmental kyphotic change after central corpectomy.

**Methods**

**Patient Population**

Records were screened from a total of 110 patients who underwent central corpectomy, fusion, and plating for CSM between 2002 and 2012 at Sri Sathya Sai Institute of Higher Medical Sciences. Sixty-seven patients who were ultimately included in the study were those who had preoperative MR images and radiographs, a postoperative lateral radiograph, follow-up dynamic lateral radiographs stored in the hospital imaging system, and a minimum follow-up of 6 months. Patients with ossified posterior longitudinal ligaments and those who had undergone a previous cervical decompressive surgery were excluded from the study. There were 61 males and 6 females in the study group (mean age 52 ± 10.37 years). The mean preoperative Nurick grade was 3.46 ± 0.69 (range 2–5), and the mean duration of symptoms was 27.34 ± 9.48 months (range 6–96 months). Twenty-two patients (32.83%) complained of neck pain at presentation.

**Normative Population**

Age- and sex-matched subjects with normal cervical spine MR images were selected from the neurosciences outpatient department for comparison of their paraspinal muscle morphometry with that of the study group. These subjects did not report neck or radicular pain, previous neck trauma, or any symptoms attributable to CSM, and had undergone cervical spine MRI as part of a screening protocol during their neurological evaluation.

**Surgical Procedure**

All patients underwent central corpectomy and fusion with autologous iliac bone graft and rigid cervical plating. The surgical protocol, including the grafting and plating technique, was uniformly adhered to by all the surgeons who conducted these surgeries (S.T., D.M., S.V.F., N.A.S.K., R.D., S.A., and A.S.H.). Surgery was performed with the patient’s neck kept extended by maintaining a folded sheet under the shoulder. A right-sided approach was used in all cases. Skull traction was maintained by use of Gardner-Wells tongs. The width of the corpectomy was 14–16 mm. After drilling off the posterior cortex, the posterior longitudinal ligament was excised in all cases. Additional manual traction was provided during placement of an autologous iliac bone graft. Anterior cervical plating was performed with self-tapping screws and titanium plates from one of the following systems: Orion/Zephir (Medtronics), CSLP (Synthes), or Trinica Select (Zimmer). After radiographic confirmation of proper placement of the graft and implant, the patients were mobilized with a hard cervical collar that they wore for 3 months postoperatively. One-level corpectomy was performed in 39 patients, 2-level corpectomy in 27 patients, and 3-level corpectomy in 1 patient.

**Radiological Evaluation**

The same imaging protocols were used for measurements in both the control and study groups. The CSA measurement method was based on the technique standardized by Elliott et al.\textsuperscript{6,7} Digital images of the preoperative cervical spine MRI and dynamic cervical radiographs, an immediate postoperative lateral cervical radiograph, and follow-up dynamic cervical radiographs of the study patients were retrieved from the hospital radiographic system (Synapse, Fujifilm Health Systems). Magnetic resonance images were acquired on a HDi 1.5-T magnet (GE Signa) using a standard NeuroVascular coil. Measurement parameters were as follows: 26 slices, slice thickness and gap 3.7 mm, FOV 180 × 188 mm, TR 4360 msec, TE 98.2 msec, matrix size 160 × 256, 1.5 excitations, flip angle 90°.

Axial sections of conventional T2-weighted spin-echo images were obtained parallel to the disc spaces. From these images, the sections at the upper vertebral endplates from C-3 to C-7 were used in the study for the measurement of the cross-sectional area (CSA) of the paraspinal muscles. The measured flexors included the sternocleidomastoid (superficial flexor), longus colli, and longus capitis (DFs). The extensors included the multifidus and semispinalis cervicis (DEs), and the semispinalis capitis, splenius capitis, and upper trapezius (superficial extensors; Fig. 1). The CSA measurement was performed by creating a region of interest for each muscle bilaterally. Perpendicular lines from the lateral border of the facets

![Fig. 1. Axial T2-weighted MRI section demonstrating measurement of the CSA of different muscle groups and vertebral body by creating regions of interest. DE = deep extensor; DF = deep flexor; SE = superficial extensor; SF = superficial flexor; VB = vertebral body.](image-url)
were used as standardized lateral limits for the region of interest for the superficial extensors.

Given that strong correlations have been established between muscle mass and skeletal CSA,\textsuperscript{26,29} we assumed that the muscle areas in our study should biomechanically correspond to the morphometry of the vertebral body at any given level. Muscle CSA–vertebral body CSA ratios (rather than absolute muscle CSA values) were thus used to eliminate biases arising out of variations in the build of the patient. The same axial MRI sections were used for measurement of both the muscle areas and the CSA of the vertebral bodies (vertebral body area, or VBA).

Two consultant neurosurgeons (S.T. and D.M.) functioned as independent observers for all measurements. The mean values of the sum of the muscle CSAs on either side at all levels, and the means of the following ratios, were then calculated: (DF) CSA/VBA, (DE) CSA/VBA, (DF) CSA/(DE) CSA, total flexor (TF) CSA/VBA, total extensor (TE) CSA/VBA, and (TF) CSA/(TE) CSA. Considering that the deep paraspinal muscles have been implicated in postural control and stability of the cervical spine,\textsuperscript{1} only the deep muscle ratios were analyzed for their effect on postoperative sagittal outcome.

Fusion was defined as the presence of the following features on radiography: 1) absence of radiolucent lines/area across the fusion site or around any of the screw sites; 2) presence of bridging trabeculae across the fusion site; and 3) absence of motion between the spinous processes on dynamic radiographs. The segmental angle was calculated as the Cobb angle between the perpendiculars drawn from 2 lines: one at the superior endplate of the superior vertebra and the other at the inferior endplate of the inferior vertebra of the fused segment (Fig. 2 left). The height of the fused segment was taken as the distance between the midpoints of these lines (Fig. 2 right). As for the paraspinal muscle area measurement, these measurements were obtained in all cases by 2 independent observers. Segmental angles of more than +5° were considered lordotic, while the remaining were considered straight or kyphotic. Based on previous publications,\textsuperscript{3,31} a change in segmental angle more than 10° and decrease in graft height of more than 2 mm were considered significant. The curvature of the whole spine was classified as lordotic, straight, or kyphotic, based on the relationship of the vertebral bodies to a line joining the posterior-most points on the inferior endplates of C-2 and C-7.\textsuperscript{31}

Follow-Up

The mean duration of follow-up was 20.48 ± 11.25 months (range 6–90 months). An improvement of Nurick grade by 1 or more was considered functional “improvement.”

Statistical Methodology

Data were entered into a Microsoft Excel spreadsheet and analyzed using SPSS version 17 (SPSS Inc.). Means and standard deviations were computed for continuous variables. The paired t-test was used to compare differences between the area ratios in the normative population and in the study cohort. Multivariate regression analysis was used to predict various muscle area ratios from independent variables that included a range of demographic and preoperative clinicoradiological factors. Pearson’s correlation was used to analyze the correlations between segmental angle change at follow-up (SACF) with the deep muscle ratios, and with graft subsidence. This analysis was performed in groups based on the number of corpectomy levels, and in subgroups with preoperatively lordotic segmental angles/curvature and those with preoperatively straight or kyphotic segmental angles/curvature. Interobserver variability was calculated using the intraclass correlation coefficient (ICC). We used the ratings on agreement levels suggested by Landis and Koch.\textsuperscript{15}

Results

Muscle Areas in Normative Population Versus Cohort

The muscle area values for both flexors (superficial and deep) and extensors (superficial and deep), and the (DF) CSA/(DE) CSA ratio, were significantly higher in the normative population compared with the study cohort (p < 0.001; Table 1). The (TF) CSA/(TE) CSA ratio was not significantly different in the two groups (p = 0.24).

Fusion and Mean Change in Graft Height and Segmental Angle

Based on the radiological criteria for fusion listed above, 59 patients (88.05%) achieved fusion of their grafts, while 8 (11.94%) demonstrated pseudarthrosis on follow-up radiography. The mean change in graft height (follow-up vs postoperative) was 3.31 ± 2.26 mm (range 0–13.3 mm). Significant subsidence (> 2 mm) occurred in 39 patients (58.20%). There were no significant differences in the mean subsidence observed among the different plating systems used during the study. All patients demonstrated an improvement in their immediate postoperative segmental angles, with a mean segmental angle change (SAC) of +2.6° ± 3.2° (range +1° to +24°). The mean SACF, however, demonstrated a mean kyphotic change of −3.07° ± 6.78° (range +15° to −22.5°). Whereas kyphotic change occurred in 24 patients (35.82%), significant SACF (> 10°) occurred in 16 patients (23.88%).

Influence of Demographic and Clinicoradiological Factors on Muscle Area Ratios

Various independent variables (age, sex, pain, duration of symptoms, preoperative Nurick grade, preoperative segmental angle, and preoperative curvature) were tested for their ability to predict various muscle area ratios. Assessing the overall fit of the multivariate regression model (Table 2), the variables were found to significantly predict (TE) CSA/VBA and (TF) CSA/(TE) CSA. Of the variables tested, age and female sex independently predicted a lower (TE) CSA/VBA (p < 0.001), while the duration of symptoms predicted (TF) CSA/(TE) CSA (p = 0.02). None of the other variables significantly predicted any of the muscle ratios.

Graft Subsidence Correlations

There was no correlation between graft subsidence
S. Thakar et al.

and SAC in the immediate postoperative period (r = 0.01, p = 0.96). Correlations between subsidence/muscle area ratios and SACF were subanalyzed in groups based on the number of corpectomy levels: single-level corpectomy versus 2-level corpectomies (Tables 3 and 4). Graft subsidence was noted to have strongly positive correlations (r = +0.40 to +0.81, p < 0.05) with SACF in the single-level corpectomy group irrespective of the preoperative segmental angle or curvature, while in the 2-level corpectomy group, it demonstrated a similar correlation only in the subgroup with preoperatively lordotic curvatures (r = 0.87, p = 0.02).

Among the muscle ratios, only the (DF) CSA/(DE) CSA ratio demonstrated correlations with SACF: a weakly negative correlation in the subgroup with preoperatively straight or kyphotic curvature in both the single- and 2-level corpectomy groups (r = −0.25, p = 0.23, and r = −0.22, p = 0.32, respectively), and a strongly negative correlation in the subgroup with preoperatively straight or kyphotic segmental angles in both the groups (r = −0.41, p = 0.04, and r = −0.53, p = 0.01, respectively).

There was no correlation of any of the muscle area ratios or of SAC with functional improvement (p < 0.05).

**Interobserver Variability**

There was almost perfect agreement in the measurement of postoperative and follow-up graft heights (ICC = 0.97 and 0.99, respectively). There was substantial agreement in the measurement of postoperative and follow-up segmental angles (ICC = 0.72 and 0.75, respectively) and in the measurement of the CSAs of the paraspinal muscles (ICC = 0.79).

**Complications**

Three patients had transient C-5 radiculopathy and 1 developed a recurrent laryngeal nerve paresis that resolved within 3 months. Four patients had wound-related problems (1 incisional hernia at the iliac bone graft site and 3 cases of superficial iliac bone graft site infection). Two patients with an intraoperative CSF leak were managed successfully with conservative treatment. There were no cases of graft or hardware failure.
Factors Affecting Cervical Paraspinal Muscle Implication and Never Analyzed.

Paraspinal muscles in CSM

**TABLE 1: Values of the muscle area ratios in the normative population compared with those in the study cohort**

<table>
<thead>
<tr>
<th>Muscle Area Ratio</th>
<th>Normative Cohort</th>
<th>Study Cohort</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(DF) CSA/VBA</td>
<td>0.54 ± 0.02</td>
<td>0.32 ± 0.06</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(DE) CSA/VBA</td>
<td>1.38 ± 0.19</td>
<td>0.59 ± 0.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(DF) CSA/(DE) CSA</td>
<td>1.40 ± 0.10</td>
<td>0.56 ± 0.15</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(TF) CSA/VBA</td>
<td>2.25 ± 0.03</td>
<td>1.41 ± 0.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(TE) CSA/VBA</td>
<td>2.16 ± 0.01</td>
<td>1.14 ± 0.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(TF) CSA/(TE) CSA</td>
<td>0.66 ± 0.41</td>
<td>0.73 ± 0.27</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* Data for the two cohorts given as means ± SDs.

**Discussion**

The cervical spine is related to a complex arrangement of superficial and deep paraspinal muscles that contribute to the static and dynamic control of the head and neck. Morphological differences in these muscles result in a variation in their biomechanical effect on the spine. Thus, while the superficial muscles assist in voluntary neck movements, the deep muscles are morphologically meant to aid the cervical posture and lordosis. Assessment of paraspinal muscle morphometry or function is of significance in preventive physiotherapy and rehabilitative postural corrections. In CSM, a condition with strong physiotherapy connotations when mild and in the post-operative setting, many clinicoradiological factors have been extensively studied in relation to outcome after surgical intervention. Changes in paraspinal muscle morphometry and their relationship with postoperative sagittal alignment in CSM have, however, only been implicated and never analyzed.

Factors Affecting Cervical Paraspinal Muscle Anthropometry and Function

Various aspects of paraspinal muscle CSA and function have been studied previously, both in normal subjects and in specific disease groups. The strength of cervical paraspinal muscles has been shown to directly correspond to their CSA, and this extrapolation adds clinical significance to anthropometry-related studies. Physiological factors such as age, bone mineral density, hormonal influences, body mass index, activity levels, and physical training have been shown to alter paraspinal muscle CSA or function. The strength of cervical extensors has been demonstrated to be stronger than the flexors, with the maximum extension-flexion isometric ratio estimated to range between 1.40 and 1.70 in normal subjects. Age and axial pain-related fat infiltration in paraspinal muscles has been another subject of interest, and has been found to variably affect the flexors and extensors.

Two common pathologies in which cervical paraspinal muscle function has been noted to change are whiplash-associated disorders and neck-pain disorders. Deep flexor dysfunction appears to be the hallmark in both these conditions. Affected subjects clinically demonstrate altered neuromotor behavior during craniocebral flexion, characterized by reduced activity in the DFs and increased activity in the superficial flexors. Furthermore, the DFs in these patients display reduced isometric endurance. Deep paraspinal muscles are predominantly comprised of Type I fibers and have a high density of muscle spindles. The effect on afferent input from these fibers due to deep muscle changes may explain the disturbances in precise movement control, proprioceptive function, and kinesthetic sense in these disorders.

In our study on a population with CSM, the generalized atrophy noted in all muscle groups as compared with normative subjects could have occurred secondary to factors such as immobilization- or pain-related disease, pain-related fatty infiltration, or as a lower motor neuron manifestation at the level of compression. In the presence of generalized atrophy, the occurrence of a weaker (DF) CSA/(DE) CSA ratio in the study group underscores significant DF atrophy in CSM. A longer duration of symptoms predisposed patients to a higher (TF)/(TE) CSA ratio, indicating that the related atrophy was more pronounced in the extensor muscles. While age and female sex demonstrated a deleterious effect on the CSA of the extensor muscles, the preoperative pain status surprisingly did not influence paraspinal muscle morphometry. Given that pain thresholds are known to have racial variations, one could conjecture that different pain thresholds in our study group masked the correlations of pain with paraspinal muscle changes, as reported earlier in other populations.

**TABLE 2: Results of a multivariate regression analysis to predict various muscle area ratios from independent variables**

<table>
<thead>
<tr>
<th>Muscle Area Ratio</th>
<th>F Value (df)†</th>
<th>p Value</th>
<th>R²‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>(DF) CSA/VBA</td>
<td>0.73 (6, 27)</td>
<td>0.63</td>
<td>0.14</td>
</tr>
<tr>
<td>(DE) CSA/VBA</td>
<td>1.57 (6, 40)</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>(DF) CSA/(DE) CSA</td>
<td>0.66 (6, 39)</td>
<td>0.68</td>
<td>0.09</td>
</tr>
<tr>
<td>(TF) CSA/VBA</td>
<td>1.74 (6, 53)</td>
<td>0.12</td>
<td>0.16</td>
</tr>
<tr>
<td>(TE) CSA/VBA</td>
<td>4.74 (6, 50)</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td>(TF) CSA/(TE) CSA</td>
<td>2.51 (6, 57)</td>
<td>0.03</td>
<td>0.20</td>
</tr>
</tbody>
</table>

* The independent variables were age, sex, duration of symptoms, pain, preoperative Nurick grade, preoperative segmental angle, and preoperative spine curvature. Bold values indicate statistical significance.
† F value in ANOVA table.
‡ Multiple correlation coefficient.

Segmental Angle Change at Follow-Up

Kypnotic alteration in the sagittal alignment of the cervical spine is known to predispose to chronic neck pain and accelerated adjacent-segment disease. Factors that have been variably associated with SACF after anterior surgery with fusion are graft subsidence, degree of kypnotic correction during surgery, preoperative spinal alignment, and range of movement of the fused segment. Given that associations such as that of subsidence with SAC have been inconsistent and have demonstrated differences based on the preoperative spinal and segmental alignment, the roles of paraspinal muscles and ligaments have been implicated in influencing SAC.
Our study establishes for the first time that paraspinal muscles do have an association with SAC, albeit in some subgroups of patients. While subsidence influenced SAC in all patients undergoing a single-level corpectomy, this influence was notably reduced in patients undergoing 2-level corpectomies. The (DF) CSA/(DE) CSA ratio demonstrated a protective effect on sagittal outcome in all patients with straight or kyphotic spines and angles irrespective of the number of corpectomy levels.

Effect of Muscle Area and SAC on Functional Outcome

There was no impact of the muscle areas, the deep muscle differential ratio, or SAC on functional improvement in our study. The lack of association of SAC and functional improvement has been reported in previous publications as well.23,31 It may be cautioned, however, that our results have been reported after relatively short follow-up periods. Longer follow-up may yield different associations between muscle area or SAC and functional outcome.

Study Implications

The fact that the (DF) CSA/(DE) CSA ratio was found to be significantly weaker in the CSM population, and that it negatively correlated with kyphotic change in some subgroups, underscores its protective influence in normal subjects and its role in maintaining segmental alignment. Having been proven to be dysfunctional in whiplash-associated disorders and neck pain, the DF CSA is conceivably an important factor in CSM biomechanics as well. Atrophy of the deep muscles (with a larger number of Type 1 fibers) extrapolates to impaired proprioception, and this in turn probably resulted in a compensatory overactivity of the superficial flexors, as has been reported elsewhere.4,11 This overall biomechanical disturbance of the flexor muscles correlated with poor sagittal outcomes. The clinical implication of this finding is that DF physiotherapy (craniocervical flexion training) should be an important component in the armamentarium of the physiotherapist treating patients with CSM. This is of practical significance considering that extensor muscle strengthening is usually the easy gain after cervical rehabilitative physiotherapy.9

The second implication of our clinical study relates to the comparative influence of ligaments and paraspinal muscles in postoperative sagittal outcomes. Computational model studies in hypolordotic spines have demonstrated a concentration of biomechanical stresses in the facets33 and a 70% increase in the elongation magnitudes in the facetal ligaments as compared with those in lordotic spines.28 These features have been postulated to result in laxity of the facet joint, alteration of segmental kinematics, and a predisposition to an overall, accelerated degenerative process.28 In our study, none of the paraspinal muscle area ratios influenced SAC in lordotic spines (with intact ligaments and presumably good biomechanics). The influence of a muscle area ratio, the (DF) CSA/(DE) CSA, on SAC was obvious only in hypolordotic spines and segments (that is, in the presence of facetal ligament laxity). This can be taken to mean that ligaments, and specifically the facetal ones, are more pivotal than paraspinal muscles in influencing SAC.

Study Limitations

The study is limited by a relatively small sample size, which causes concern that it may be underpowered to detect effects on functional outcome. Secondly, it has the inherent limitations of being a retrospectively designed study. Thus, although the study suggests that craniocervical flexion training protocols may alter the clinical course of CSM, randomized controlled trials in this regard are

### TABLE 3: Subgroup analysis of correlation of different factors with SACF in patients undergoing single-level corpectomy*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Lordotic Segmental Angle</th>
<th>Curvature</th>
<th>Straight/Kyphotic Segmental Angle</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>graft subsidence</td>
<td>0.77 (0.00)</td>
<td>0.81 (0.00)</td>
<td>0.40 (0.02)</td>
<td>0.49 (0.01)</td>
</tr>
<tr>
<td>(DF) CSA/VBA</td>
<td>0.16 (0.53)</td>
<td>0.39 (0.19)</td>
<td>-0.12 (0.62)</td>
<td>-0.29 (0.17)</td>
</tr>
<tr>
<td>(DE) CSA/VBA</td>
<td>0.01 (0.96)</td>
<td>0.14 (0.62)</td>
<td>0.27 (0.25)</td>
<td>0.03 (0.87)</td>
</tr>
<tr>
<td>(DF) CSA/(DE) CSA</td>
<td>-0.12 (0.63)</td>
<td>-0.20 (0.25)</td>
<td>-0.41 (0.04)</td>
<td>-0.25 (0.23)</td>
</tr>
</tbody>
</table>

* Data given as r correlation (p value). Bold values indicate statistical significance.

### TABLE 4: Subgroup analysis of correlation of different factors with SACF in patients undergoing 2-level corpectomy*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Lordotic Segmental Angle</th>
<th>Curvature</th>
<th>Straight/Kyphotic Segmental Angle</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>graft subsidence</td>
<td>0.06 (0.83)</td>
<td>0.87 (0.02)</td>
<td>0.07 (0.77)</td>
<td>0.28 (0.19)</td>
</tr>
<tr>
<td>(DF) CSA/VBA</td>
<td>0.02 (0.93)</td>
<td>0.36 (0.44)</td>
<td>-0.34 (0.21)</td>
<td>-0.24 (0.27)</td>
</tr>
<tr>
<td>(DE) CSA/VBA</td>
<td>0.12 (0.68)</td>
<td>0.48 (0.08)</td>
<td>0.31 (0.24)</td>
<td>0.19 (0.37)</td>
</tr>
<tr>
<td>(DF) CSA/(DE) CSA</td>
<td>-0.16 (0.58)</td>
<td>-0.02 (0.96)</td>
<td>-0.53 (0.01)</td>
<td>-0.22 (0.32)</td>
</tr>
</tbody>
</table>

* Data given as r correlation (p value). Bold values indicate statistical significance.
warranted. Longer follow-up durations may have yielded different results. Lastly, a repeat CSA assessment at follow-up may have provided additional information on morphometry changes in paraspinal muscles after intervention. However, a previous study on patients undergoing anterior cervical discectomy and fusion had shown that the CSA of extensor muscles did not change significantly at long-term follow-up and that this mild change did not correlate with the development of axial symptoms.37

Conclusions

Patients with CSM demonstrate generalized atrophy in their superficial and DF and DE muscles as compared with normal subjects. These patients also suffer a reduction in the protective effect of a strong DF/DE ratio, a factor that affects SAC in patients with hypolordotic segments or spines. Considering that the influence of a muscle ratio was significant only in patients with hypolordosis, a subgroup that is known to have facetal ligament laxity, it may also be postulated that ligamentous support supersedes the influence of paraspinal muscles on postoperative sagittal alignment in CSM.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Thakar, Furtado, Hegde. Acquisition of data: Thakar, Mohan, Rao. Analysis and interpretation of data: Thakar, Mohan, Furtado, Saikiran, Dadlani, Aryan. Drafting the article: Thakar, Aryan. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Thakar. Statistical analysis: Thakar.

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J Neurosurg: Spine / Volume 21 / August 2014 229

Manuscript submitted July 2, 2013.
Accepted April 24, 2014.
Please include this information when citing this paper: published online May 30, 2014; DOI: 10.3171/2014.4.SPINE13627.
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