



Clinical study

Fatty infiltration of the cervical extensor musculature, cervical sagittal balance, and clinical outcomes: An analysis of operative adult cervical deformity patients



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ABSTRACT

Purpose: To assess preliminary associations between fatty-infiltration (FI) of cervical spine extensor musculature, cervical sagittal balance, and clinical outcomes in cervical deformity (CD) patients.

Methods: Operative CD patients (C2-C7 Cobb > 10°, CL > 10°, cSVA > 4 cm, or CBVA > 25°) with pre-operative (BL) MRIs and 1-year (1Y) post-operative MRIs or CTs were assessed for fatty-infiltration of cervical extensor musculature, using dedicated imaging software at each C2-C7 intervertebral level and the apex of deformity (apex). FI was gauged as a ratio of fat-free-muscle-cross-sectional-area (FCSA) over total-muscle-CSA (TCSA), with lower ratio values indicating greater FI. BL-1Y associations between FI, sagittal alignment, and clinical outcomes were assessed using appropriate parametric and non-parametric tests.

Results: 22 patients were included (Age 59.22, 71.4%F, BMI 29.2, CCI:0.75, Frailty: 0.43). BL deformity presentation: TS-CL: 29.0°, C2-C7 Sagittal Cobb:-1.6°, cSVA:30.4 mm. No correlations were observed between BL fatty-infiltration, sagittal alignment, frailty, or clinical outcomes ($p > 0.05$). Following surgical correction, C2-C7 (BL: 0.59 vs 1Y:0.67, $p = 0.005$) and apex (BL: 0.59 vs. 1Y: 0.66, $p = 0.33$) fatty-infiltration decreased. Achievement of lordotic curvature correlated with C2-C7 fatty infiltration reduction ($R_s: 0.495$, $p < 0.05$), and patients with residual postoperative TS-CL and cSVA malalignment were associated with greater apex fatty-infiltration ($R_s: -0.565$, -0.561 ; $p < 0.05$). C2-C7 FI improvement was associated with NRS back pain reduction ($R_s: -0.630$, $p < 0.05$), and greater apex fatty-infiltration at BL was associated with minor perioperative complication occurrence ($R_s: 0.551$, $p = 0.014$).

Conclusions: Deformity correction and sagittal balance appear to influence the reestablishment of cervical muscle tone from C2-C7 and reduction of back pain for severely frail CD patients. This analysis helps to understand cervical extensor musculature's role amongst CD patients.

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1. Introduction

Cervical paraspinal musculature plays an important role in the maintenance of horizontal gaze, neutral alignment, and distribution of the cranial load through flexion, extension and translational motions. In a normally aligned lordotic cervical spine, the posterior tension band and extensor cervical musculature counterbalance anteriorly directed forces from the cranial load, maintaining neutral alignment and a horizontal gaze [1,2]. Cervical spine deformity, often degenerative in etiology or arising from compensatory mechanisms for subjacent thoracolumbar deformity, typically manifests in alteration of anterior column integrity, progressive cranial load-bearing shifts toward the anterior column, and kyphotic malalignment [3–5]. Biomechanically, anterior cranial load shifts and kyphotic changes induce a larger forward bending movement force relative to the cervical spines fulcrum of rotation, requiring greater paraspinal extensor musculature contraction for compensation of cranial load shifts and maintenance of horizontal gaze. Deformity induced stress and progressive malalignment resulting in unequal distribution of cranial load forces on the cervical extensor musculature may propagate in extensor muscular fatigue, chronic pain, muscular atrophy and asymmetric muscle tone [1].

Despite the interdependence of cervical alignment and extensor musculature function, few studies quantitatively describe this relationship. Previous research investigating normative adult populations show fatty infiltration of lumbar multifidus and paraspinal muscles to be associated with high-intensity low back pain, disability, and structural abnormalities [6,7]. Increased rates of fatty infiltration in spinal and hip extensor musculature—key musculature in the maintenance of sagittal alignment—have also been observed in degenerative lumbar and adult spinal deformity patients [8,9]. Previous investigations of cervical extensor musculature have primarily focused on whiplash patients, as fatty infiltration of deep extensor musculature is commonly observed in patients with chronic whiplash associated disorders [10,11]. While neck pain has been shown to be associated with reduced activation of deep cervical extensor musculature in a normative population [2], fatty infiltration of cervical extensor musculature has not been shown to be associated with the insidious onset of chronic neck or shoulder pain post whip-lash injury [12].

The quantitative relationship between cervical extensor muscle atrophy and cervical malalignment in cervical deformity patients is understudied in the literature. This study aims to use computed tomography and magnetic resonance imaging to investigate the effect of deformity correction on extensor musculature, to assess fatty infiltration of the cervical spine extensor musculature, and to describe the associations between muscle atrophy (i.e. fatty infiltration), sagittal malalignment, functionality, and pain.

2. Methods

2.1. Study inclusion criteria

This study was a retrospective review of prospectively and consecutively enrolled adult patients (≥ 18 years) presenting to three surgeons at two academic centers for cervical spine deformity. Cervical deformity was defined utilizing baseline radiographic imaging, according to the following established radiographic criteria: cervical kyphosis (C2–7 sagittal Cobb angle $\geq 10^\circ$), cervical scoliosis (C2–7 coronal Cobb angle $\geq 10^\circ$), C2–C7 sagittal vertical axis (C2–C7 SVA) ≥ 4 cm, or chin-brow vertical angle (CBVA) $\geq 25^\circ$. Institutional Review Board (IRB) approval was obtained at the home institution prior to enrolling patients.

2.2. Data collection

Patient demographic data included age, sex, race, and body mass index (BMI). Baseline comorbidities include history of smoking, osteoporosis, and Charlson Comorbidity Index (CCI). Clinical symptom data included bowel issues, bladder issues, abnormal gait, hand clumsiness, hand numbness, L'Hermitte test, bilateral paresthesia, weakness, corticospinal motor deficits, hand muscle atrophy, hyperreflexia, Hoffman's test, lower limb spasticity, upgoing plantar response. Patient frailty status was also assessed, utilizing the previously published cervical deformity frailty index (CD-FI), with scores of <0.2 defined as not frail, 0.2 – 0.4 defined as frail, and >0.4 defined as severely frail. Surgical data collected included number of levels fused, surgical approach, decompression type (discectomy, foraminectomy, corpectomy, laminectomy), osteotomy type (incomplete/complete facet, Smith-Petersen Osteotomy [SPO], opening/closing wedge). Clinical outcomes were evaluated with the modified Japanese Orthopaedic Association (mJOA) score, Neck Disability Index (NDI), Numeric Rating Scale (NRS) Neck and Back pain at baseline and 1-year post-operative follow-up. Peri-operative complications related to surgical treatment were also recorded.

Collected imaging included baseline T2-weighted magnetic resonance images (MRI) and 1-year post-operative MRI or computed tomography (CT) imaging with axial and sagittal views, as well as baseline and 1-year post-operative cervical and long-standing anterior-posterior and lateral radiographs, as per standard of care by the enrolling surgeons. Radiographic measurements for x-rays were analyzed using validated software programming (SpineView; ENSAM Laboratory of Biomechanics, Paris, France) at a single academic center. Cervical sagittal alignment and balance was evaluated using cervical lordosis (C2–C7 Sagittal Cobb Angle: angle between the lower endplates of C2 and C7), cervical sagittal vertical axis (cSVA: C2 plumbline offset from the posterosuperior corner of C7), T1 slope (T1SS: the angle between a horizontal line and the upper end plate of T1, described as overall spinal sagittal balance) and the mismatch between T1 slope and CL (TS-CL). MRI/CT measurements were evaluated using dedicated software (Surgimap Spine; Nemaris Inc., New York, NY) [13]. Calibration for measurements was available from each DICOM image, allowing for quantitative assessment of cervical extensor musculature (multifidus, semispinalis cervicis, semispinalis capitis, splenius capitis, levator scapulae) (Fig. 1). Muscle measurements of interest included total muscle cross-sectional area (TCSA), functional muscle cross-sectional area (FCSA) representing fat-free muscle area, and a ratio of FCSA to TCSA as an indication of muscle composition (i.e. fatty infiltration). The TCSA and FCSA were measured in axial T2-weighted images by constructing polygon points around the outer margins of the total extensor musculature area, and individual paraspinal extensor muscles. The number of points selected for each image varied according to the shape and size of the muscle, and the polygon generated reflected the shape of the musculature (Figs. 2 and 3). Threshold signal intensities within the TCSA were utilized in construction of FCSA polygon points. The FCSA/TCSA ratio was used to quantify paraspinal extensor muscle atrophy, with lower ratio values indicating an increased degree of fatty deposition. Paraspinal cervical extensor musculature measurements were obtained at each intervertebral level from C2 to C7 (C2–C3, C3–C4, C4–C5, C5–C6, C6–C7) and at the apex of deformity [8,14–17].

2.3. Statistical analysis

All statistical analyses were performed using SPSS software (Version 23.0, Armonk, NY, USA). Shapiro-Wilk test assessed variables for normality. Frequencies, means and standard deviations of demographic variables, clinical symptoms, surgical details, and muscle measurements of interest were calculated. Parametric

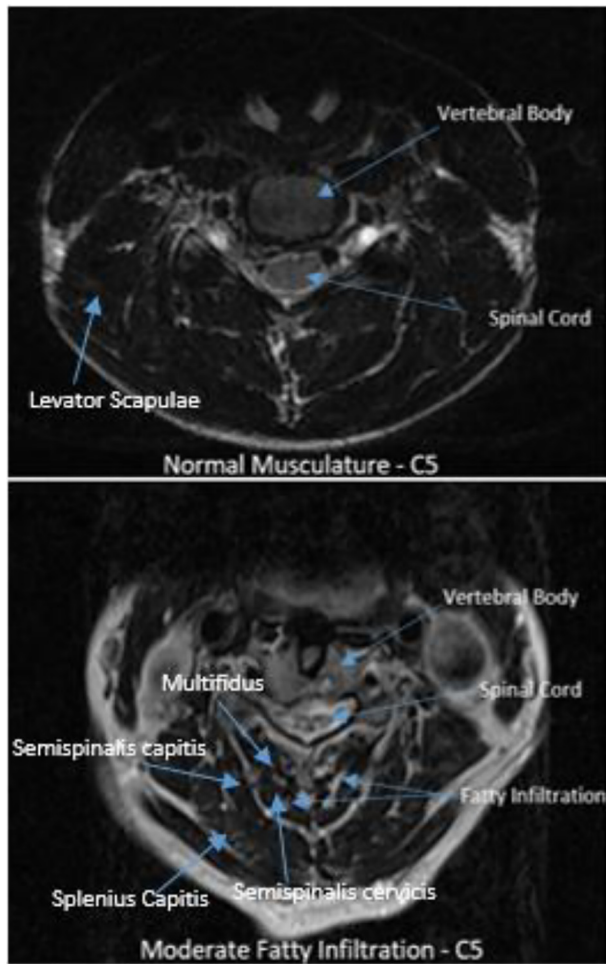


Fig. 1. Anatomy of the axial cervical spine of a patient with normal musculature, and a Patient with moderate fatty infiltration. Specified anatomical features included the vertebral body, spinal cord, multifidus muscles, semispinalis capitis muscles, splenius capitis muscles, semispinalis cervicis muscles, and levator scapulae at the C5 level.

(paired t-tests) and non-parametric (Wilcoxon Signed-Ranks test) related means comparisons were utilized appropriately, comparing TCSA, FCSA, and FCSA/TCSA ratios at all intervertebral levels. Spearman's rank correlations gauged associations between muscle mass measurements (mean C2-C7 FCSA/TCSA ratio, apex TCSA/TCSA ratio), demographic variables, clinical symptoms, baseline and postoperative sagittal radiographic alignment parameters, PROMs, and perioperative complications. Patients were also stratified on the basis of whether C2-C7 Sagittal Cobb angle demonstrated substantial lordosis (C2-C7 Sagittal Cobb $\geq 13^\circ$) or kyphosis (C2-C7 Sagittal Cobb $\leq -6^\circ$) [18,19], and associations between muscle measurements were assessed for each group, relative to patients without substantial lordosis or kyphosis. All statistical tests were 2-tailed, and $p < 0.05$ was considered statistically significant.

3. Results

3.1. Pre-operative patient characteristics

21 operative cervical deformity patients were included. Mean patient age was 60.0 years old, 75.0% were female, 75.0% were white, 20.0% black, 5.0% Asian, 15.0% were smokers, and 20.0% had osteoporosis. Patients on average were over-weight (BMI 29.1), severely frail (mFI 0.43), and of mild comorbidity severity (CCI: 0.79). The greatest drivers of deformity were located in the

cervical spine (57%), followed by the cervico-thoracic junction (24%), and thoracic regions (5.0%). Patients presented with severe TS-CL malalignment (30.0 ± 16.4), neutral C2-C7 Sagittal Cobb alignment (-0.4 ± 14.4), and mildly malaligned cSVA (33.6 ± 16.4) and T1-Slope (29.4 ± 13.8). 47.7% of patients presented with cervical kyphosis, while 21.2% presented with substantial cervical lordosis. 58% of patients were neurologically symptomatic, with the most prevalent symptoms being overall weakness (58%), hand numbness (37%), and hand clumsiness (32%). Regarding PROMs, patients reported substantial neck (7.8/10) and back pain (5.8/10), severe functional disability (NDI: 53.1 ± 17.8), myelopathy symptoms (mJOA: 13.6 ± 2.5), and a low quality of life (EQ5D: 0.71) (Table 1).

3.2. Correlations between Baseline patient Characteristics and muscle measurements

Regarding preoperative fatty infiltration (FCSA/TCSA) ratio from C2-C7 and at the apex of deformity, no significant associations were observed amongst patient demographics, sagittal radiographic parameters, frailty or PROMs (all $p > 0.05$). A positive L'Hermitte sign (R_s 0.478) and lower limb spasticity (R_s 0.532) were positively correlated with FCSA/TCSA ratio at the apex of deformity ($p < 0.05$). (Table 2)

3.3. Surgical details

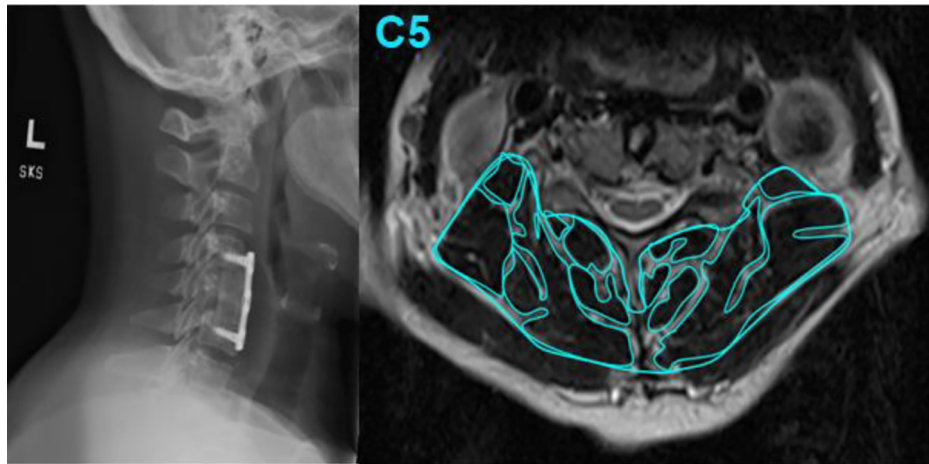
The most common surgical approach was the posterior approach (11 patients, 50.0%), followed by combined approaches (10 patients, 45.5%) and the anterior approach (1 patient, 4.5%). The average construct length was 7.9 ± 3.8 levels fused, 19 (87.4%) patients received a decompression (45.5% Corpectomy, 45.5% Discectomy, 18.2% Foraminotomy), and 19 (87.4%) patients received an osteotomy (45.5% partial facet, 36.4% Smith Peterson, 18.2% complete facet). 1 patient had a vertebral column resection, 1 patient had a pedicle subtraction osteotomy, and 2 patients had a laminectomy. Average operative time was 667.7 min, average EBL was 985.7ccs. 72.7% of patients had a perioperative complication (major: 13.6%, minor: 59.1%), 27.3% of which were intraoperative (major: 0%, minor: 27.3%).

Patients with less muscle fatty infiltration at the apex of deformity (increased FCSA/TCSA ratios) correlated with lower levels fused (R_s -0.524 , $p < 0.05$), less EBL (R_s -0.478 , $p < 0.05$) and lower rate of minor perioperative complication occurrence (R_s -0.551 , $p < 0.05$) (Table 2).

3.4. 1-Year postoperative outcomes

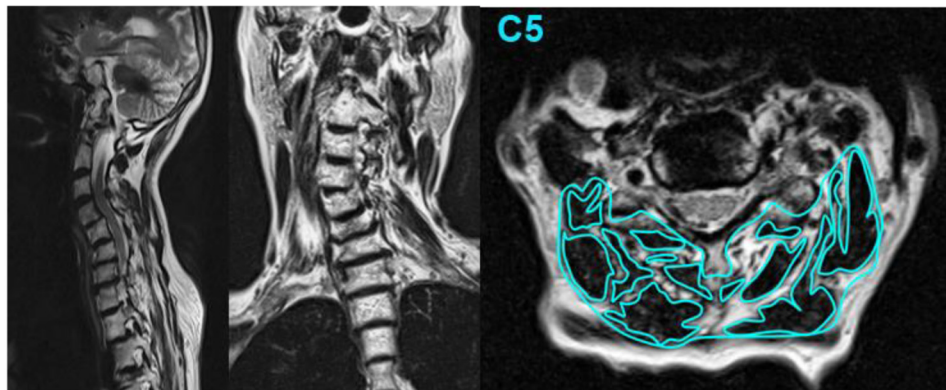
At 1-year follow-up after operative correction, fatty infiltration of the cervical extensor muscles significantly improved from C2-C7 (FCSA/TCSA Ratio-BL: 0.58 vs Y1: 0.67, $p = 0.002$) and at the apex of deformity (FCSA/TCSA Ratio- BL: 0.59 vs Y1: 0.66, $p = 0.026$). Baseline mean TCSA was 3965.1 ± 1490 and 3384.4 ± 801.0 at 1 year post op. Baseline FCSA was 2180.4 ± 2218.3 and 2218.29 ± 316.6 at 1 year post op. Baseline and 1-Year postoperative TCSA, FCSA, and FCSA/TCSA ratio values for all intervertebral levels can be found in Table 3.

No significant changes were observed between preoperative and postoperative sagittal alignment measures, although C2-C7 sagittal Cobb angle trended towards significant correction (BL: -1.6 vs. Y1: 6.1, $p = 0.089$), and global SVA trended towards increased malalignment (BL: -22.4 vs Y1: 28.7, $p = 0.072$). Significant improvements to patient frailty (mFI BL: 0.43 vs Y1: 0.28, $p = 0.002$), overall neurologic symptom prevalence (BL: 60% vs Y1: 23.8%, $p = 0.018$), hand clumsiness (BL: 35% vs. Y1: 4.8%, $p = 0.031$), hand numbness (BL: 40.0% vs. 9.5%, $p = 0.031$), and



Parameter	Baseline Value
TS – CL (°)	13.55
cSVA (mm)	11.95
C2-C7 Sagittal Cobb (°)	8.4
mJOA Score	14
Fatty Infiltration Ratio	0.60

Fig. 2. Case Example – Muscle measurements of a patient with minimal deformity. Thoracic slope minus cervical lordosis (TS-CL), cervical sagittal vertical axis (cSVA), C2-C7 sagittal cobb angle, mJOA scores, and the fatty infiltration ratio (FCSA/TCSA) are shown for the C5 level.



Parameter	Baseline Value
TS – CL (°)	37.14
cSVA (mm)	66.7
C2-C7 Sagittal Cobb (°)	-11.7
mJOA Score	15
Fatty Infiltration Ratio	0.51

Fig. 3. Case Example – Muscle measurements of a patient with significant deformity. Thoracic slope minus cervical lordosis (TS-CL), cervical sagittal vertical axis (cSVA), C2-C7 sagittal cobb angle, mJOA scores, and the fatty infiltration ratio (FCSA/TCSA) are shown for the C5 level.

weakness (BL: 55% vs. Y1: 19.0%, $p = 0.016$) were observed following surgery. Improvements to PROMS were also observed, with patients reporting significantly less neck pain (NRS Neck- BL: 7.7 vs Y1: 5.0, $p = 0.004$), less disability (NDI-BL: 55.7 vs Y1: 42.4, $p = 0.011$), and improved quality of life (EQ5D- BL: 0.71 vs Y1: 0.76, $p = 0.049$) (Table 1).

3.5. Correlations between Baseline to 1-year changes in muscle measurements, radiographic parameters, and PROMS

Achievement of lordotic curvature significantly correlated with improvement to the C2-C7 FCSA/TCSA ratio (R_s 0.495, $p < 0.05$). Improvement to the C2-C7 FCSA/TCSA ratio also significantly cor-

Table 1

Analysis of Means and/or Frequencies of Baseline and 1-Year Postoperative Patient Demographics, Ames Deformity Descriptors, Sagittal Radiographic Parameters, Clinical Symptoms, and PROMs.

Patient Characteristics	Preoperative Mean (SD) or %	1-Year Postoperative Mean (SD) or %	p-value
Demographics			
Sample Size	22		
Age	59.2 ± 9.4		
Gender (Female)	71.4%		
Race			
White	71.4%		
Black	23.8%		
Hispanic	–		
Asian	4.8%		
BMI	29.2 ± 6.0	27.9 ± 6.9	0.300
CCI	0.75 ± 0.91		
Frailty (CD-FI)	0.43 ± 0.06	0.28 ± 0.16	0.002
Smoking Status (yes)	14.3%		
Osteoporosis	19.0%		
Ames Deformity Driver Descriptors			
Cervical (C)	65.0%	–	–
Cervico-Thoracic (CT)	25.0%	–	–
Thoracic (T)	5.0%	–	–
Coronal (S)	5.0%	–	–
Cranio-Vertebral Junction (CVJ)	0%	–	–
Sagittal Radiographic Parameters			
TS-CL (°)	29.0 ± 15.6	28.1 ± 11.0	0.827
C2-C7 Cobb (°)	–1.6 ± 14.9	6.1 ± 12.1	0.089
Lordotic	21.4% (22.3°±8.3)	29.4% (21.1°±8.4)	0.764
Kyphotic	35.3%	20.0%	0.310
	(–17.1 ± 0.2)	(–11.2 ± 2.4)	
cSVA (mm)	30.4 ± 16.0	29.1 ± 9.9	0.601
T1-Slope (°)	30.8 ± 11.1	36.3 ± 12.9	0.107
Pelvic Tilt (°)	16.2 ± 11.8	19.2 ± 9.0	0.255
SVA (mm)	–22.4 ± 44.0	28.7 ± 95.6	0.072
PI-LL (°)	–8.3 ± 16.5	–4.1 ± 19.2	0.242
Clinical Symptoms			
Any Neurological Symptom	60.0%	23.8%	0.018
Bladder Impairment	10.0%	0.0%	0.500
Bowel Impairment	10.0%	0.0%	0.500
Gait Impairment	25.0%	4.8%	0.125
Hand Clumsiness	35.0%	4.8%	0.031
Hand Numbness	40.0%	9.5%	0.031
L'Hermitte Sign (positive)	10.0%	0.0%	0.500
Bilateral Paresthesia	20.0%	4.8%	0.250
Weakness (general)	55.0%	19.0%	0.016
Corticospinal Motor Deficits	30.0%	4.8%	0.063
Hand Muscle Atrophy	25.0%	14.3%	0.500
Hypereflexia	20.0%	0.0%	0.125
Hoffman's Sign (positive)	20.0%	0.0%	0.125
Lower limb spasticity	15.0%	0.0%	0.250
Upgoing plantar response	10.0%	0.0%	0.500
Disability, Functionality, and Pain Scores (PROMs)			
NRS Neck Pain	7.7 ± 2.1	5.0 ± 3.5	0.004
NRS Back Pain	5.9 ± 2.9	6.1 ± 3.1	0.784
NDI	55.7 ± 17.3	42.4 ± 23.5	0.011
mJOA	13.6 ± 2.5	14.6 ± 2.9	0.168
EQ5D	0.71 ± 0.07	0.76 ± 0.12	0.049

*Bolded p-values indicates statistical significance. BMI: Body Mass Index; mFI: modified Frailty Index; TS-CL: T1 Slope minus Cervical Lordosis; cSVA: cervical Sagittal Vertical Axis; NRS: Numeric Rating Scale; NDI: Neck Disability Index; mJOA: modified Japanese orthopaedic association questionnaire; EQ5D: Euroqol 5-dimension questionnaire.

related with reduction of NRS Back pain (R_s –0.630, $p < 0.05$) (Table 4).

3.6. Correlations between 1-Year postoperative muscle measurements, radiographic parameters, proms, surgical details, and Ames modifiers

At 1-year postoperative follow-up, alignment of TS-CL (R_s –0.565, $p < 0.05$) and cSVA (R_s –0.561, $p < 0.05$) was signifi-

Table 2

Correlations between preoperative muscle measurements, patient demographics, preoperative radiographic parameters, clinical symptoms, PROMs, and surgical details.

Preoperative Muscle Measurements	C2-C7 FCSA/TCSA Ratio (R_s)	Apex FCSA/TCSA Ratio (R_s)
Demographics		
Age	–0.162	–0.152
Gender (Female)	–0.017	–0.352
BMI	–0.147	0.125
CCI	–0.041	0.198
mFI	0.142	–0.027
Smoking Status	–0.045	–0.356
Osteoporosis	–0.240	–0.236
Preoperative Radiographic Parameters		
TS-CL (°)	0.232	0.009
C2-C7 Cobb (°)	–0.341	–0.248
Lordosis	–0.324	–0.518
Kyphosis	0.226	–0.154
cSVA (mm)	–0.275	–0.345
T1-Slope (°)	–0.277	–0.134
Pelvic Tilt (°)	0.061	0.217
SVA (mm)	–0.015	0.062
PI-LL (°)	0.211	0.283
Preoperative Clinical Symptoms		
Any Neurologic Symptom		
Bladder	–0.231	0.068
Bowel	–0.231	0.068
Gait	–0.010	0.215
Hand Clumsiness	0.155	0.253
Hand Numbness	0.212	0.324
L'Hermitte	0.058	0.478*
Bilateral Paresthesia	0.000	0.284
Weakness (general)	0.009	–0.119
Corticospinal Motor Deficits	–0.076	0.216
Hand Muscle Atrophy	0.030	0.287
Hypereflexia	0.087	0.335
Hoffman's Sign	–0.217	0.103
Lower limb spasticity	–0.012	0.532*
Upgoing plantar response	–0.260	0.409
Preoperative Disability, Functionality, and Pain Scores (PROMs)		
NRS Back	0.088	0.221
NRS Neck	0.092	0.220
NDI	0.396	0.146
mJOA	0.061	–0.191
EQ5D	–0.274	–0.344
Surgical Details		
Levels Fused	0.023	–0.524*
Op-Time	–0.089	0.011
EBL	–0.113	–0.482*
Intra-Op Complications	–0.121	–0.059
Major	–	–
Minor	–0.361	–0.311
Peri-Op Complications	0.121	–0.193
Major	–0.135	0.157
Minor	–0.112	–0.551*

Bolded values with an * indicate significance of $p < 0.05$. Bolded values with ** indicate significance of $p < 0.01$. BMI: Body Mass Index; mFI: modified Frailty Index; TS-CL: T1 Slope minus Cervical Lordosis; cSVA: cervical Sagittal Vertical Axis; NRS: Numeric Rating Scale; NDI: Neck Disability Index; mJOA: modified Japanese orthopaedic association questionnaire; EQ5D: Euroqol 5-dimension questionnaire.

cantly associated with improvement to fatty infiltration at the apex of deformity. Patients who experienced a perioperative complication were also significantly associated with a worse C2-C7 FCSA/TCSA ratio (R_s –0.584, $p < 0.05$), FCSA/TCSA ratio at the apex of deformity (R_s –0.704, $p < 0.05$). Patients who experienced a major perioperative complication were associated worse FCSA/TCSA ratio values at the apex of deformity (R_s –0.650, $p < 0.05$). No associations were observed between postoperative fatty infiltration, PROMs, or achievement of lowest level Ames modifiers. (Table 5)

Table 3
Baseline to 1-Year Postoperative Changes amongst Muscle Measurements.

Baseline and 1-Year Post-Operative Muscle Measurements									
Cervical Muscle Mass Measurements									
Level	TCSA (Mean ± SD)(mm ²)		FCSA (Mean ± SD)(mm ²)			FCSA/TCSA Ratio (Mean ± SD)			
	Baseline	1-Year	p	Baseline	1-Year	p	Baseline	1-year	p
C2-C3	5387.4 ± 2908.1	3783.7 ± 1147.3	0.027	2392.5 ± 808.9	2294.8 ± 418.2	0.666	0.49 ± 0.14	0.62 ± 0.10	0.004
C3-C4	3634.9 ± 965.1	3237.1 ± 905.6	0.296	1936.1 ± 443.3	2122.2 ± 332.7	0.223	0.54 ± 0.08	0.68 ± 0.09	0.004
C4-C5	3731.2 ± 1673.9	3204.6 ± 1056.5	0.163	2143.1 ± 855.2	2144.0 ± 580.9	0.997	0.59 ± 0.08	0.69 ± 0.09	0.019
C5-C6	3631.6 ± 1778.2	3139.2 ± 769.3	0.274	2253.8 ± 1308.5	2169.7 ± 454.0	0.827	0.61 ± 0.08	0.71 ± 0.10	0.009
C6-C7	3505.5 ± 1039.5	3550.0 ± 739.9	0.881	2217.9 ± 621.8	2358.7 ± 532.8	0.604	0.64 ± 0.09	0.67 ± 0.12	0.301
Mean C2-C7	3965.1 ± 1490.4	3384.4 ± 801.0	0.069	2180.4 ± 2218.3	2218.29 ± 316.6	0.830	0.58 ± 0.06	0.67 ± 0.08	0.002
Apex of Deformity	Baseline		1-Year			p			
FCSA/TCSA Ratio	0.59 ± 0.10		0.66 ± 0.07			0.026			

Bolded p values indicate significance. TCSA: Total Muscle Cross Sectional Area, FCSA: Functional Muscle Cross Sectional Area.

Table 4
Correlations between Baseline to 1-Year Postoperative Change in Muscle Measurements, Sagittal Radiographic Alignment Parameters, and PROMs.

BL to 1-Year Postoperative Δ Muscle Measurements	Δ C2-C7 FCSA/TCSA Ratio (R _s)	Δ Apex FCSA/TCSA Ratio (R _s)
<i>Postoperative Radiographic Parameter Δ</i>		
Δ TS-CL (°)	-0.200	-0.383
Δ C2-C7 Cobb (°)	0.245	0.321
Δ Lordosis	0.495*	0.000
Δ Kyphosis	0.267	0.134
Δ cSVA (mm)	0.418	-0.370
Δ T1-Slope (°)	-0.024	-0.214
Δ Pelvic Tilt (°)	-0.188	0.283
Δ SVA (mm)	0.017	-0.236
Δ PI-LL (°)	-0.055	-0.217
<i>Postoperative Disability, Functionality, and Pain Scores (PROMs) Δ</i>		
Δ NRS Back	-0.630*	0.453
Δ NRS Neck	-0.127	0.078
Δ NDI	-0.396	0.014
Δ mJOA	-0.221	-0.190
Δ EQ5D	0.407	0.068

Bolded values with an * indicate significance of p < 0.05. Bolded values with ** indicate significance of p < 0.01. TCSA: Total Muscle Cross Sectional Area, FCSA: Functional Muscle Cross Sectional Area, TS-CL: T1 Slope minus Cervical Lordosis; cSVA: cervical Sagittal Vertical Axis; NRS: Numeric Rating Scale; NDI: Neck Disability Index; mJOA: modified Japanese orthopaedic association questionnaire; EQ5D: Euroqol 5-dimension questionnaire.

4. Discussion

Fundamental function of the cervical spine includes distribution of the cranial load, maintenance of horizontal gaze, preservation of neurovascular structures, and allowance of normal range of motion. Cervical paraspinal musculature plays a key role in maintenance of horizontal gaze, neutral alignment, and distribution of the cranial load through flexion, extension and translational motions. Cervical malalignment may induce anteriorly directed forces and unequally distribute the cranial load across the cervical paraspinal musculature, requiring chronic asymmetric contraction of the extensor musculature, resulting in muscular fatigue, chronic pain, and muscular atrophy. To the best of our knowledge, no studies have yet described the relationship between cervical paraspinal musculature, sagittal alignment, and disability in operative cervical deformity patients.

Our investigation of 22 operative cervical deformity patients showed no associations between preoperative fatty infiltration of extensor musculature, sagittal radiographic parameters, or PROMs. A previous study by Inoue and colleagues, studying a population of 188 individuals without a previous diagnosis of cervical deformity or history of spinal surgery reported similar results, finding no association between cervical lordotic alignment and muscle fatty

degeneration [20]. The negative results of the present study may be the result of a relatively homogenous patient cohort and inadequate sample size. Only 22 patients were investigated within our study, and all were classified as having cervical deformity, limiting the potential for substantial variability and statistical power. In order to more accurately assess the associations between fatty infiltration, radiographic alignment, and PROMs, more heterogeneous cohorts (including severe, moderate, mild, and non-cervical deformity patients) and greater sample sizes are needed.

Our results show that following re-stabilization, decompression, and realignment of the cervical spine via spinal fusion and decompression procedures, fatty infiltration of the cervical extensor musculature at the C2-C7 intervertebral levels and the apex of deformity improve by 1-year postoperative follow-up. Achievement of lordotic curvature was associated with the reduction of C2-C7 fatty infiltration. A recent biomechanical study by Patwardhan et al. [21] investigated the kinematic, kinetic, and muscular responses to cervical sagittal imbalance, finding increased C2-C7 cSVA (i.e. increased forward head position) to be associated with reduction of lower cervical nerve root compression, shortening of the cervical flexor and occipital extensor muscles, and lengthening of the cervical extensor and occipital flexor muscles, corresponding to C2-C7 flexion and C0-C2 extension. The greatest shortening was also observed in the sub-occipital muscles (C0-C1-C2), suggesting considerable load bearing of the sub-occipital extensor muscles (C0-C2), and load alleviation of the cervical extensor muscles (C2-C7) during chronic forward head position. It is possible, then, that correction of deformity to a neutral position may redistribute cranial load forces back to the cervical C2-C7 extensor musculature and increase muscular tone. Indeed, our results show an overall reduction of C2-C7 extensor muscle fatty infiltration in our patient population at the 1-year postoperative interval. Patients with residual 1-year postoperative TS-CL and cSVA malalignment in our cohort were also showed greater fatty infiltration of the cervical extensor musculature at the apex of deformity, further supporting the association between correction of cervical sagittal deformity and increased muscular tone.

Patwardhan et al also found that increasing T1-slope (a component of TS-CL) predominantly influenced sub-axial cervical lordosis, suggesting that increased forward head position may compensate for upper thoracic kyphosis, muscular burden, and nerve root compression (lower cervical neural foraminal area) causing radicular symptoms. Within our cohort, postoperative improvement of fatty infiltration from C2-C7 significantly correlated with reduction of patient reported back pain (NRS Back). We speculate that the association between improvement in post-operative C2-C7 fatty muscle infiltration and back pain reduction reflects successful redistribution of cranial load forces through cervicothoracic realignment and improvement to lower cervical nerve root compression [21].

Table 5
Correlations between 1-Year Postoperative Patient Characteristics, Sagittal Alignment Parameters, PROMs, Clinical Symptoms, Ames Modifiers, and Surgical Details.

1-Year Postoperative Muscle Measurements	C2–C7 FCSA/TCSA Ratio (R_s)	Apex FCSA/TCSA Ratio (R_s)
<i>Demographics</i>		
BMI	–0.179	0.156
mFI	–0.345	–0.375
<i>Postoperative Achievement of Lowest Level Ames Modifiers</i>		
Ames cSVA	0.139	0.476
Ames TS-CL	0.362	0.308
Ames mJOA	–0.416	–0.319
<i>1-Year Postoperative Radiographic Parameters</i>		
TS-CL (°)	–0.371	–0.565*
C2–C7 Cobb (°)	0.280	0.323
Lordosis	0.190	0.229
Kyphosis	–0.311	0.000
cSVA (mm)	–0.294	–0.561*
T1-Slope (°)	–0.214	–0.190
Pelvic Tilt (°)	–0.188	–0.219
SVA (mm)	–0.200	0.086
PI-LL (°)	–0.418	–0.304
<i>1-Year Postoperative Clinical Symptoms</i>		
Any Neurologic Symptom	–0.316	–0.316
Bladder	–	–
Bowel	–	–
Gait	–	–
Hand Clumsiness	–	–
Hand Numbness	0.044	–0.131
L'Hermitte	–	–
Bilateral Paresthesia	–	–
Weakness (general)	0.139	0.084
Corticospinal Motor Deficits	–	–
Hand Muscle Atrophy	–0.130	–0.163
Hyperreflexia	–	–
Hoffman's Sign	–	–
Lower limb spasticity	–	–
Upgoing plantar response	–	–
<i>1-Year Postoperative Disability, Functionality, and Pain Scores (PROMs)</i>		
NRS Back	–0.369	–0.235
NRS Neck	0.201	0.285
NDI	0.063	0.160
mJOA	–0.276	–0.092
EQ5D	0.067	0.023
<i>Surgical Details</i>		
Levels Fused	–0.372	0.106
Op-Time	0.210	0.039
EBL	–0.268	–0.212
Intra-Op Complications	0.046	–0.457
Major	–	–
Minor	0.016	–0.415
Peri-Op Complications	–0.584*	–0.705*
Major	–0.259	–0.650*
Minor	–0.345	–0.487

Bolded values with an * indicate significance of $p < 0.05$. Bolded values with ** indicate significance of $p < 0.01$. TCSA: Total Muscle Cross Sectional Area, FCSA: Functional Muscle Cross Sectional Area, TS-CL: T1 Slope minus Cervical Lordosis; cSVA: cervical Sagittal Vertical Axis; NRS: Numeric Rating Scale; NDI: Neck Disability Index; mJOA: modified Japanese orthopaedic association questionnaire; EQ5D: Euroqol 5-dimension questionnaire.

Lastly, within our cohort, patients with more preoperative fatty infiltration at the deformity apex showed increased rates of minor perioperative complications. Patients who experienced a perioperative complication were also had increased C2–C7 and Apex fatty infiltration at 1-year postoperative follow-up. While the association between complication occurrence and fatty muscle infiltration is unclear, greater preoperative fatty infiltration was also correlated with longer longer fusion constructs. Longer fusion constructs, despite being indicative of greater deformity severity, also predispose patients to an increased chance of complication occurrence due to the increased invasiveness of the surgery and longer postoperative recovery period [22–24].

Among the limitations of this study are a lack of statistical power due to a small sample size of 22 patients, a relatively homogenous cohort of cervical spine deformity patients, and the lack of a non-deformed control group. To more accurately assess associations between fatty infiltration, radiographic alignment, and PROMs, more heterogeneous cohorts (including severe, moderate, mild, and non-cervical deformity patients, as well as patients with coronal deformities) and greater sample sizes are needed. In addition, we evaluated fatty infiltration of musculature using both CT and MRI's. While we believe our dedicated software used for image measurements minimizes the difference between assessing both modalities, variation across imaging modalities may affect the accuracy of our findings. Furthermore, isolating TCSA and FCSA utilizing the polygon point technique in cases of severe fatty infiltration posed a challenge due to extensive muscle degeneration, and may be subject to increased bias [8]. Although no associations were observed between gender and fatty infiltration within this study, there is substantial evidence in the literature that differences in fatty acid metabolism exist between males and females [25]. No attempts were made to control for sex bias within this study.

5. Conclusion

This investigation describes the relationships between cervical sagittal balance, fatty infiltration of the cervical extensor musculature, and patient reported outcomes (PROMs) in a cohort of operative cervical deformity patients. Realignment of lordotic cervical curvature via spinal fusion was associated with a reduction of C2–C7 fatty muscle infiltration at 1-year postoperative. Mean C2–C7 fatty muscle infiltration was shown to decrease following surgery, and patients with postoperative residual C2–C7 cSVA and TS-CL malalignment were also associated with greater fatty infiltration at the apex of deformity at 1-year postoperative. Our results suggest that correction of C2–C7 cSVA and TS-CL to a neutral position redistributes cranial load forces from C0–C2 suboccipital extensor muscles to the C2–C7 extensor musculature, resulting in greater overall postoperative C2–C7 extensor muscle tone. Reduction of C2–C7 fatty muscle infiltration also correlated with NRS back pain improvement, which may be reflective of successful realignment resulting in redistribution of cranial load forces and alleviation of lower cervical nerve root compression associated with cervicothoracic malalignment.

Ethical review committee statement

Each institution obtained approval from their local Institutional Review Board to enroll patients in the prospective database and informed consent was obtained from each patient.

Conflicts of interest related to current work

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jocn.2019.12.044>.

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