

The Role of Cervical Muscles Morphology in the Surgical Treatment of Degenerative Disc Disease: Clinical Correlations Based on Magnetic Resonance Imaging Studies

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Abstract

Cervical spine musculature still remains a less studied component of the cervical spine anatomical compartments, although it plays a significant role in the mobility of the head and the preservation of cervical spine alignment. The goal of this study was to extract any significant information from the literature regarding the role of cervical spine muscles morphology in the outcome of surgically treated patients for degenerative disc disease (DDD) based on preoperative magnetic resonance imaging (MRI) studies. Eleven clinical case series were found, from which four were prospective and seven were retrospective. Six studies were concentrated on anterior approaches and five studies on posterior approaches in the cervical spine. In posterior approaches aiming at the preservation of muscles attachments and overall less surgical manipulations, results on cervical lordosis, axial pain and patient's functionality were found superior to traditional laminectomies. The study of cross-sectional areas (CSAs) of deep paraspinal muscles in the cervical spine could add significant information for the spine surgeon such as the prediction of adjacent level disease (ALD), fusion failure, axial pain persistence, postoperative cervical alignment and patient's postoperative functionality. It seems that MRI studies focusing on muscle layers of the cervical spine could add significant information for the spinal surgeon regarding the final surgical outcome in terms of pain and function expres-

sion. Larger multicenter clinical studies are a necessity in defining the role of the muscle component of the cervical spine in the surgical treatment of DDD.

Keywords: Cervical spine; Degenerative disease; Magnetic resonance imaging; Muscles

Introduction

Degenerative disc disease (DDD) is one of the most frequently encountered conditions in everyday clinical practice resulting in chronic back and neck pain, spinal instability and inevitably in functionality impairment [1, 2]. The diminution of quality of life and depressive illness are some of the common findings among patients with DDD [2, 3]. There is a consensus among scientists regarding the mechanism of DDD that aging along with environmental and genetic factors lead to cellular and structural alterations of the intervertebral disk, affecting its mechanic properties [2, 4, 5]. Consequently, nearby connective tissue structures undergo functional impairment and degeneration as well [4, 5]. The associated neural elements may be compromised via mechanical compression or inflammatory process, which may warrant surgical treatment. Thus, clinical manifestations of spine degeneration could range from chronic pain to acute neurological deficits and myelopathy signs such as spasticity and gait impairment [2, 6]. Tobacco use, diabetes, malnutrition, hip arthritis, spine trauma, hard physical work, lack of exercise and obesity have been linked with increased risk of DDD [2, 7].

Mainly two components are responsible for the mechanical stability of the neck, the cervical musculature (80%) and the osseo-ligamentous system (20%) [8, 9]. Although the osseo-ligamentous system has been meticulously studied during the last decades, cervical musculature still remains a less studied component of the neck with several recognized significant roles. According to the literature, cervical muscles preserve the cervical alignment, and contribute significantly in the mobility of the neck and the stabilization of the head. Neck pain, pathological alignment and decreased range of motion for example, could be the result of dysfunction of extensor cervical spine

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muscles [10, 11].

As stated in many studies in the past, cervical muscle volume tends to decrease in time with subsequent decline of the muscular strength even in asymptomatic populations and with preference in males [12-14]. Cervical spine muscle volume decrease becomes more apparent between the fifth to sixth decade of life and it has been found to be associated with shoulder stiffness when it affects deep extensor cervical muscles [14]. One of the most ordinary findings in magnetic resonance imaging (MRI) studies of the cervical spine is fat infiltration of the muscles [15]. Fat infiltration is associated with reduction of cervical lordosis and neck stiffness [16-18].

Surgical treatment of cervical spine pathologies requires cervical muscle manipulation either imperceptible as in anterior approaches where the muscles are usually divided, or significant as in posterior approaches where the muscles are detached from the spine. Although the literature is filled with studies concerning the multifactorial role of the muscles of the cervical spine, there is a lack of case series of surgically treated patients focusing on the role of cervical spine muscle layers to the clinical and surgical outcome.

Our goal is to identify in the current literature case series of surgically treated patients for degenerative cervical spine disease where any information regarding cervical musculature, based on preoperative MRI studies, has been recorded and used by the authors. Furthermore, our intention is to demonstrate the impact of cervical musculature in cervical lordosis alternations as well as pain and patient's functional outcome.

Materials and Methods

A search through the PubMed database was conducted from January 1990 to December 2020 using the following terms: "anterior," "cervical," "discectomy," "functional," "fusion," "laminectomy," "lordosis," "magnetic resonance imaging," "muscles," "operation," "procedure," "posterior," and "surgery". Only English language titles, abstracts, articles, and their references were retrieved. We included all the surgical series of patients that were treated for DDD and/or myelopathy in their cervical spine. Case series that recorded measurements of cervical muscles of any kind as well as patients' postoperative functional outcome were studied thoroughly. Additionally, any other information regarding cervical lordosis changes and pain scores were also recorded.

Results

According to our search, eleven studies were found, four of which were prospective and seven retrospective. Six studies were concentrated on anterior approaches (Table 1 [19-23]) and five studies on posterior approaches in the cervical spine (Table 2 [24-29]).

Anterior approaches

In their retrospective study, Choi et al (2016) focused on the

relationship between deeply located paraspinal muscles and fusion after an anterior cervical spine procedure in 243 patients [19]. Authors studied the cross-sectional area (CSA) of these muscles and the related fusion based on bone union after anterior cervical discectomy and fusion (ACDF) surgery with a stand-alone cage at C5/C6 or C6/C7 levels. The CSAs included measurements of longus colli, longus capitis, semispinalis cervicis, and multifidus muscles based on magnetic resonance images. Postoperative dynamic radiographs were used for the evaluation of bone fusion. Patients were divided into two groups based on adequate/successful or inadequate fusion. According to their statistical results, extensor semispinalis cervicis and multifidus muscles were significantly heterogeneous among the two groups. More specifically, increased dimensions of extensor semispinalis cervicis at C5/C6 level was found positively correlated with a successful and quicker fusion process.

In another prospective study, Matsumoto et al (2012) studied the changes of posterior cervical spine muscles 10 years after an ACDF surgery in comparison to healthy subjects [20]. Authors enrolled 31 patients that were operated with an ACDF approach and 32 healthy adults as control group. A follow-up MRI was carried out on both groups and CSAs of deeply located posterior muscles were compared at C3/C4, C4/C5 and C5/C6 levels. According to their measurements posterior cervical muscles varied significantly between the two groups with only a small depletion in the CSA in the ACDF group. These changes were not significantly correlated to pain or functionality scores as in posterior approaches.

Similarly, Thakar et al (2014) in their retrospective case control study focused on the impact of superficial, deep flexors and deep extensors cervical paraspinal muscles in patient's functionality and cervical sagittal alignment after a cervical corpectomy with fusion and plating for cervical spondylotic myelopathy (CSM) [21]. Sixty-seven patients were enrolled in this study. Authors collected data of CSAs of the paraspinal muscles based on axial MR images of T2-weighted sequence and calculated them as ratios in relation to the corresponding vertebral body areas (VBAs) and additionally as flexor/extensor CSA ratios. The calculated fractions were correlated to the same fractions of normal subjects. In addition, these ratios were correlated to other parameters such as pain scores, Nurick grade and segmental angle change after surgery. Statistical analysis revealed that normal population had significant higher ratios than patients group ($P < 0.001$). Higher age patients and female patients had a lower total extensor CSA/VBA ratio ($P < 0.001$), while a longer period of clinical manifestations of CSM significantly prognosticated a higher total flexor/total extensor CSA ratio ($P = 0.02$). Amongst the fractions reflecting the muscle areas, the deep flexor (DF)/deep extensor (DE) fraction was found negatively correlated with segmental angle change in the subdivision of patients with preoperative straight or kyphotic segmental angles ($P = 0.04$ in the single corpectomy group, $P = 0.01$ in the two-level corpectomy group). There was not any statistically significant correlation of any of the calculated muscle fractions with Nurick grade alteration.

In continuation of his research background, Thakar et al (2019) prospectively studied 45 patients with single-level ra-

Table 1. MRI-Based Studies of Cervical Spine Musculature of Patients That Underwent an Anterior Approach for Degenerative Disc Disease

Authors/year of publication	Type of study	Number of patients	Type of surgery	Conclusions
Choi et al, 2016 [19]	Retrospective case-control study	243 divided in fusion and no fusion groups	ACDF	Increased dimensions of extensor semispinalis cervicis at C5/C6 level was found positively correlated with a successful and quicker fusion process.
Matsumoto et al, 2012 [20]	Prospective case-control study	31 patients that were operated with ACDF approach, and 32 healthy adults as control group	ACDF	Posterior cervical muscles were not different significantly between the two groups with only a small decrease in the cross-sectional area (CSA) in the ACDF group. These changes were not significantly correlated to pain or functionality scores.
Thakar et al, 2014 [21]	Retrospective case-control study	67 patients with cervical spondylotic myelopathy and normal subjects	Anterior cervical corpectomy-fusion-plating	Normal population has significant higher ratios of CSAs of the superficial, deep flexor (DF), and deep extensor (DE) paraspinal muscles than patients' group ($P < 0.001$). Higher age patients and female patients had 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 ($P = 0.02$). Among the muscle area ratios, the DF/DE ratio demonstrated a negative correlation with segmental angle change in the subgroup with preoperative straight or kyphotic segmental angles ($P = 0.04$ in the single corpectomy group, $P = 0.01$ in the two-level corpectomy group). There was no correlation of any of the muscle ratios with change in Nurick grade.
Thakar et al, 2019 [22]	Prospective study	45 patients with single level radiculopathy-myelopathy or myelopathy	ACDF	Deep flexors areas as well as the ratio of deep flexors areas to deep extensors areas have a significant prognostic value of Nurick grade improvement.
Wong et al, 2020 [23]	Retrospective case-control study	32 patients with adjacent level disease after a two-level ACDF procedure; 30 patients that did not have this complication	ACDF	Asymmetry of fat at C5 (coefficient: 0.06), standardized measures of C7 lean (coefficient: 0.05) and total CSA measures (coefficient: 0.05) were the strongest predictors of early onset ASD.

MRI: magnetic resonance imaging; ACDF: anterior cervical discectomy and fusion; VBA: vertebral body area; ASD: adjacent segment degeneration.

diculopathy (myelopathy or myelopathy) that underwent an anterior cervical discectomy (ACD) procedure [22]. The main goal was to record all the possible predictors of the surgical outcome, as stated from the literature, and to study their significance. Many parameters were taken into consideration such as age, gender, smoking, other comorbidities, duration of symptoms, preoperative Nurick grade, extent of cord compression, and signal intensity change in the spinal cord. Additionally, MRI-based CSAs of the superficial and deep paraspinal muscles were included. According to author's statistics, deep flexors' areas as well as the ratio of deep flexors' areas to deep extensors areas have a significant prognostic value of Nurick grade improvement.

Lastly, another research group retrospectively studied the predictive value of morphology of semispinalis cervicis and multifidus muscles in adjacent level degeneration disease after ACD and fusion surgery [23]. Wong et al (2020) created two matched groups of patients. One group had 32 patients with adjacent level disease after a two-level ACDF procedure. The other group had 30 patients with a normal postoperative course. The total CSA of deep neck muscles and lean muscles from C3 to C7 was calculated focusing in asymmetry on each

operated level by using T2-weighted MRI. An algorithm was used in order to predict proximal or distal adjacent segment degeneration (ASD) which was supported by a vector machine. According to the results of this study, the used algorithm predicted early ASD with high accuracy (96.7%). Fat asymmetry at C5 (coefficient: 0.06), standardized measures of C7 lean (coefficient: 0.05) and total CSAs measures (coefficient: 0.05) were the dominant predictors of early onset ASD.

Posterior approaches

Ashana et al (2017) compared the presence of paraspinal muscle atrophy between patients that were operated with laminoplasty and patients that were operated with laminectomy and fusion [24]. Both groups of patients were operated for CSM. Atrophy was recorded as percentage change in CSAs of the cervical paraspinal muscles from preoperative to postoperative MRI studies. Authors found a 2.19 times increase of the degree of atrophy in patients who sustained laminectomy and fusion. This study concluded that paraspinal muscle atrophy is correlated to anatomically extended surgical procedures where

Table 2. MRI-Based Studies of Cervical Spine Musculature of Patients That Underwent a Posterior Approach for Degenerative Disc Disease

Authors/year of publication	Type of study	Number of patients	Type of surgery	Conclusions
Ashana et al, 2017 [24]	Retrospective study	61	18 laminoplasty and 43 laminectomy and fusion patients	Authors found a 2.19 times increase of the degree of atrophy in patients who sustained laminectomy and fusion. This study concluded that paraspinous muscle atrophy is correlated to anatomically larger surgical procedures.
Chen et al, 2019 [25]	Retrospective study	63	36 patients with laminoplasty and posterior muscle-ligament complex preservation, and 27 patients with traditional laminoplasty	The preservation of posterior muscle-ligament complex protects patients from a postoperative muscle volume decrease which was noted in the traditional laminoplasty patients' group ($P < 0.01$).
Kim et al, 2020 [26]	Retrospective study	106	Cervical laminoplasty	Higher T1 slope and less regional cross-sectional areas at C7 - T1 level were associated with loss of cervical lordosis.
Kotani et al, 2009 [27]	Retrospective study	84	conventional open-door laminoplasty and deep extensor muscle-preserving laminoplasty	Laminoplasty with deep extensor muscle-preserving approach appeared to be effective in reducing the axial pain and deep muscle atrophy, as well as improving cervical spine function and QOL when compared to conventional open-door laminoplasty.
Kotani et al, 2012 [28]	Prospective study	90	Conventional open-door laminoplasty and deep extensor muscle-preserving laminoplasty	There is a superiority of deep extensor muscle-preserving laminoplasty in terms of postoperative axial pain, QOL, and prevention of atrophy of the deep extensor muscles over conventional open-door laminoplasty for the treatment of CSM.
Lee et al, 2018 [29]	Prospective study	144	Laminoplasty procedure	Statistical analysis revealed that high T1 slope and low summation of CSAs at each level of the semispinalis cervicis is correlated with loss of cervical lordosis. The level of the semispinalis cervicis associated with greater loss of lordosis was the C6 level.

MRI: magnetic resonance imaging; CSA: cross-sectional area; QOL: quality of life; CSM: cervical spondylotic myelopathy.

surgical manipulations and muscle detachment are more prominent [24].

Chen et al (2019) retrospectively compared the differences on surgical results between 36 patients with CSM that were treated with laminoplasty and posterior muscle-ligament complex preservation, and 27 patients with the same pathology treated with traditional laminoplasty [25]. Among others, the authors concluded that the preservation of posterior muscle-ligament complex protects patients from a postoperative muscle volume decrease which was noted in the traditional laminoplasty group of patients ($P < 0.01$). Pain scores as well as cervical sagittal balance were better in the first group of patients.

Kim et al (2020) in their retrospective study attempted to recognize predisposing factors of loss of cervical lordosis in 106 patients that underwent a cervical laminoplasty procedure [26]. Authors divided their patients in 38 that preserved cervical lordosis and in 68 patients that lost cervical lordosis. They recorded cervical sagittal parameters, neck pain scores, CSAs of the posterior cervical muscles in the operated levels and muscle fat infiltration of deep extensor cervical muscles based on preoperative MRIs. Authors concluded that besides cervical sagittal parameters such as higher T1 slope, lesser regional

CSAs at C7 - T1 level were associated with loss of cervical lordosis as well.

In their retrospective cohort study, Kotani et al (2009) compared the conventional surgical treatment of open-door laminoplasty with deep extensor muscle preserving laminoplasty in cervical myelopathy patients [27]. Besides the typical recorded parameters in surgically treated patients such as axial pain and quality of life, parameters such as radiological evaluation of cervical lordosis, range of motion and deep extensor muscle areas on specific axial MRI images were also taken into consideration. Eighty-four patients were included in this study with a minimum follow-up period of 24 months. According to the results of this study, a statistically significant difference in superior cervical spine function, quality of life, as well as pain reduction scores were noted in the muscle preserving group indicating the superiority of this method. This was supported also by the MRI radiological evaluation which demonstrated statistically significant muscle atrophy in patients that were treated by the conventional method ($P < 0.01$). In 2012, the same group of researchers published data of 90 patients that were treated for CSM with a minimum follow-up of 36 months [28]. These patients were divided also in two groups and the protocol of comparison was identical

by using the two aforementioned surgical techniques. Authors concluded that pain, functionality and muscle atrophy were statistically different in these two groups. The muscle preserving technique proved to be superior to the conventional laminoplasty.

In another similar study, Lee et al (2018) focused on the role of preoperative CSA of semispinalis cervicis muscle in the preservation of cervical lordosis after a laminoplasty procedure [29]. One hundred forty-four patients with cervical myelopathy were included in this study. Cervical sagittal balance parameters and MRI-based CSAs of semispinalis cervicis muscle were recorded for every patient. Statistical analysis showed that high T1 slope and low summation of CSAs at each level of the semispinalis cervicis were correlated with loss of cervical lordosis. The level of the semispinalis cervicis that was associated with substantial loss of lordosis was the C6 level with a max of 10 degrees reduction of cervical lordosis being noted.

Discussion

Cervical spine muscles can be divided to suboccipital region muscles and to mid to lower cervical spine muscles [30]. The last are divided based on their location to: ventrally located muscles and dorsally located muscles. The ventral muscle layer is further subdivided to: 1) superficial muscles such as platysma and sternocleidomastoid muscle; 2) deep muscle layer such as: scalenus group, longus group and infrahyoid group. In the same way, the dorsal muscle layer is further divided to: 1) superficial muscle layer such as trapezius, splenius and elevator scapulae muscles; 2) the intermediate muscle layer known as erector spinae group including semispinalis, iliocostalis, and longissimus muscles; 3) deep muscle layer group which includes the transversospinalis muscle group. Based on their function, cervical muscles can be further divided to flexors, extensors, lateral flexors and rotators (Table 3) [30].

In anterior approaches, the muscles being manipulated are the sternocleidomastoid, the platysma, omohyoid, sternothyroid and bilateral longus colli [31-35]. The spine surgeon usually divides the muscles with the exception of the platysma and the omohyoid, which can be transected, and the longus colli that normally are detached from the anterior surface of the cervical spine. In posterior approaches, the posterior paraspinal muscles are detached from the spine in order to gain access to underlying significant anatomical structures such as the spinous process, the laminae, the facets, the pedicles, the neuronal foramina, the vertebrae, the spinal canal and the spinal cord [36-44]. The degree of detachment depends on the pathology and the type of the procedure (laminectomy/laminotomies, foraminotomies, posterior fusion with screws and rods, etc). The main dorsal muscles that are affected from these surgical procedures are trapezius, splenius, semispinalis (capitis and cervicis) and longissimus depending on the operated level/levels.

MRI of the cervical spine is a commonly used imaging study that spine surgeons use preoperatively in order to extract useful information about the cervical discs and spinal

Table 3. Classification of Cervical Spine Muscles Based on Their Function

Function of cervical musculature	
Flexion	
	Sternocleidomastoid
	Longus colli
	Longus capitis
	Rectus capitis anterior
	Stylohyoid
	Digastric
	Mylohyoid
	Geniohyoid
	Omohyoid
	Sternohyoid
	Sternothyroid
Extension	
	Splenius capitis
	Splenius cervicis
	Semispinalis capitis
	Semispinalis cervicis
	Longissimus capitis
	Longissimus cervicis
	Trapezius
	Interspinal
	Rectus capitis posterior major
	Rectus capitis posterior minor
	Obliquus capitis superior
Rotation	
	Sternocleidomastoid
	Trapezius
	Splenius capitis
	Longissimus capitis
	Obliquus capitis inferior
	Rectus capitis posterior major
	Longus capitis
	Rotators
	Multifidus
Lateral flexion	
	Scalene
	Splenius capitis
	Longus colli
	Levator scapulae
	Iliocostalis cervicis
	Intertransversarii

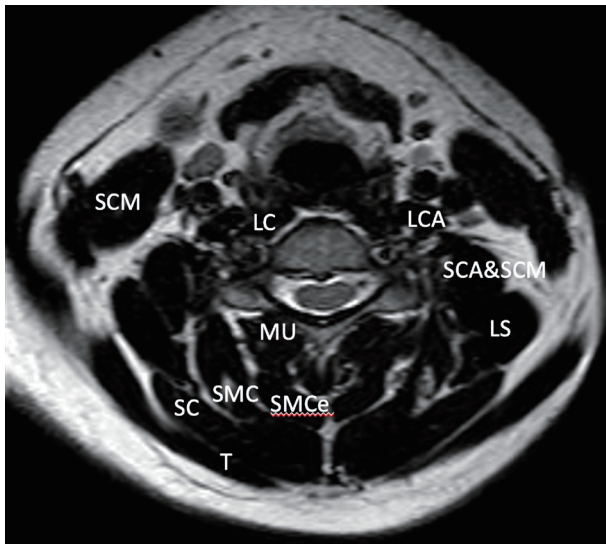


Figure 1. Axial T2 MRI image that demonstrates the muscle layers of the cervical spine of a 40-year-old asymptomatic woman at C5/C6 level. MRI: magnetic resonance imaging; LCA: longissimus capitis; LC: longus colli; LS: levator scapulae; MU: multifidus; SCA: scalenus anterior; SC: splenius capitis; SMC: semispinalis capitis; SCM: sternocleidomastoid; SMCe: semispinalis cervicis; T: trapezius.

cord morphology [45-49]. Interestingly, cervical spine MRI through several well-known MR applications such as T1, T2, proton density and gradient echo can also depict the muscle layers of the cervical spine and additionally locate pathological signal areas such as infiltrated muscle fat [16, 17, 50-52]. The collected data based on MRI studies can assist in the volume quantification as well as qualification of the cervical spine muscles morphology (Fig. 1). In the literature, there are several studies analyzing muscle morphology with a variety of imaging protocols as well as studied populations including young people, elderly people, healthy people, trauma and degenerative cases. Elliot et al in their work tried to define imaging protocols that could provide adequate information about paravertebral muscles volume and their components [51]. They spotted several different imaging protocols in the literature based on T1, T2, STIR, DIXON and T2-fat suppression sequences. Furthermore, the collected slices of interest based on axial MR images as well as the studied muscles of interest varied also significantly (by several cervical disc spaces) with manual based as well as automated based measurements of regions of interest (ROIs). Authors concluded that a multi-slice approach by using three-dimensional (3D)-MRI techniques could define muscle size and muscle fat infiltration although it requires significant effort and time [51]. High resolution MRI techniques such as 3D fat/water discrimination and proton density fat suppression/fraction can be used towards the definition of cervical muscles morphology [51]. In our literature review study, heterogeneity of imaging protocols was also noted. Measurements were focused mostly on deep paraspinal extensor muscles based on their CSAs in axial MR images at specific cervical spine levels.

Additionally, there were several studies in the past linking muscle fat infiltration and subsequently muscle's atrophy with

posttraumatic pain especially after a whiplash injury [52, 53]. This finding was noted in cervical extensors and cervical flexors of the neck of patients with whiplash cervical trauma [11]. Muscle fat infiltration is also present in cervical myelopathy patients and is highly associated with patients' reduced sensorimotor functionality and muscle volume loss [54]. In several studies, muscle fat infiltration and asymmetry of deeply located paraspinal muscles have been linked with higher Neck Disability Index scores as well as weakness and pathological pyramidal signs [55, 56]. Moreover, in a recent study, the authors expressed the opinion that muscle fat infiltration of the upper extensor muscles is linked to loss of cervical lordosis while fat infiltration of the lower extensors cervical muscles can lead to significant loss of patient's functionality [15]. In addition to that, it has been found that chronic neck pain patients have a tendency through time to present reduced balance as well as muscle atrophy combined with muscle fat infiltration [18, 57]. Worse deformity status has been found in cervical deformity patients with notable muscle fat infiltration and muscle atrophy of their posterior extensor cervical muscles [58]. Surgical treatment of cervical deformity can lead to reduction of muscle fat infiltration of posterior extensor muscles and is associated with better muscle tone and also pain diminution [59]. All these statements still need clarification as several scientists claim that pain could be the result of degeneration of the anatomical components of the cervical spine such as vertebrae, facets and discs and the correlated changes of spine curvature [20].

As the literature demonstrated, in patients with cervical degenerative disease as well as myelopathy, muscle atrophy is a common finding in patients with higher pain scores as well as higher disability scores after a cervical spine procedure especially posterior and traditional [19, 20, 24, 25, 27, 28, 60]. The preservation of the cervical muscle attachments appears to positively affect the postoperative pain score and muscle atrophy [60]. Muscle fat infiltration and CSAs measurements of deep posterior cervical spine muscles in one study can predict adjacent level degeneration disease after an ACDF procedure [23]. Furthermore, in another study optimum fusion process was noticed in patients with increased muscle volume of extensor semispinalis cervicis [19].

Regarding the role of cervical spine muscles in the preservation of cervical spine lordosis, there are many facts published in the literature supporting their strong connection. For example, botulinum toxin injection can deteriorate cervical spine kyphotic deformity [61]. Drop head syndrome can be the result of cervical spondylotic amyotrophy [62]. In general, in patients with CSM there is a significant correlation between cervical muscles morphology, clinical findings and patients' functionality [55]. Tamai et al in their study found a significant correlation between paraspinal muscle volume, cervical sagittal balance parameters and DDD based on retrospectively collected kinematic cervical spine MRI data of patients with DDD [63]. Cervical extensors isometric exercises can reduce neck pain and contribute in cervical lordosis restoration [64]. Patients with loss of cervical lordosis have less muscular strength especially in their extensors [10]. According to a recent study, cranio-cervical flexor muscles exercise can reduce neck pain and improve cervical spine lordosis [65]. Additionally, May-

oux-Benhamou et al concluded, in their study, that longus colli muscles interact with post-cervical muscle layers for the stabilization of the cervical spine and head as well as the preservation of cervical lordosis [66]. Similarly, Mitsutake et al in their study concluded that in patients with cervical spondylotic radiculopathy, muscle fat infiltration of cervical multifidus muscle is linked to postural instability even in static standing positions [67]. Furthermore, it is supported in the literature that muscle fat infiltration of the upper cervical extensors muscles can lead to loss of cervical lordosis and in the case of lower cervical extensors to functionality impairment [15]. In another published clinical study, the authors tried to correlate muscle fat infiltration with cervical motion based on cervical kinetic MRI of patients with clinical signs of radiculopathy and/or neck pain [68]. Authors concluded that presence of muscle fat infiltration was more obvious at C3, C7 levels than other intermediate cervical spine levels [68]. Cervical spine mobilization as well as lordosis was not affected by the degree of muscle fat infiltration [68].

According to our literature research study, in surgically treated patients for DDD, the strong connection between cervical lordosis and the muscle component of the cervical spine seems to be present. In anterior approaches, the ratio of deep flexor to deep extensor paraspinal muscles proved to have a negative correlation with segmental angle change in patients with straight or kyphotic segmental angles [21]. In regards to posterior approaches, there are studies supporting that less regional CSAs at C7 - T1 level and low summation of CSAs at each level of the semispinalis cervicis are correlated to reduced cervical lordosis [29]. Fusion process was studied only in anterior approaches, as it has been found that increased dimensions of extensor semispinalis cervicis at C5/C6 level, lack of fat asymmetry at C5, standardized measures of C7 lean and total CSA measures are significantly correlated with the timing of fusion and the prediction of ASD [19, 23].

Additionally, functionality expressed by Nurick scores was significantly correlated to deep flexors areas as well as the ratio of deep flexors to deep extensors areas in anterior approaches only in one study [22]. In posterior approaches, the preservation of posterior paraspinal muscles by applying new techniques demanding less muscle manipulation could lead to improved functionality and reduced pain scores [27, 28].

In conclusion, there are several surgical case series in the literature studying cervical spine musculature with large heterogeneity in patients' selection, imaging study protocols, applied measurements as well as study goals. It is remarkable that the muscle component is far less studied than the cervical spine itself. Muscle layers of the cervical spine seem to be valuable structures for the preservation of cervical lordosis, the improvement of the patients' functionality, as well as the prediction of surgical outcome in DDD. Finally, larger multicenter clinical studies could help in defining the role of the muscle component of the cervical spine in the surgical outcome of DDD.

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Conflict of Interest

None to declare.

Author Contributions

Conception and design: Ioannis Siasios and Theodosios Birbilis. All authors contributed to data acquisition, data interpretation, drafting the manuscript, critically revising the manuscript, and final approval of the manuscript.

Data Availability

The authors declare that data supporting the findings of this study are available within the article.

Abbreviations

ALD: adjacent level disease; ACDF: anterior cervical decompression and fusion; CSAs: cross-sectional areas; DDD: degenerative disc disease; DF: deep flexor; DE: deep extensor; MRI: magnetic resonance imaging; VBAs: vertebral body ar- eas

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