Preliminary evaluation of dorsal muscle activity during resisted cervical extension in patients with longstanding pain and disability following anterior cervical decompression and fusion surgery

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A preliminary evaluation of dorsal muscle activity during resisted cervical extension in patients with longstanding pain and disability following Anterior Cervical Decompression and Fusion
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ABSTRACT

Objectives: To compare mechanical activity (deformation and deformation rate) of the dorsal neck muscles between individuals with longstanding symptoms after anterior cervical decompression and fusion (ACDF) and healthy controls.

Design: A pilot cross-sectional study.

Setting: Former patients at a Neurosurgery clinic.

Participants: Ten individuals (mean age 60 years; SD 7.1) who underwent ACDF 10-13 years ago and 10 healthy age- and sex-matched controls participated in the study.

Interventions: Not applicable.

Main Outcome Measures: Measures were made at the C4 segment using ultrasonography (speckle tracking analysis) during a standardized, resisted cervical extension task.

Results: A significant group x muscle interaction was found for muscle deformation (p < 0.03) but not deformation rate (p > 0.79). Tests of simple effects revealed that the ACDF group showed significantly less deformation of the semispinalis capitis (mean (SD) for ACDF 3.12(2.06) and controls 6.64(4.17), mean difference 3.34 (95%CI -0.54 to 7.21)) during the extension task than healthy controls.

Conclusions: As the semispinalis capitis muscle is a powerful neck extensor, the finding of altered activation lend support to the inclusion of exercise to train neck muscle performance in the management of these patients.

Keywords: Extensor muscles, Neck surgery, Disc disease, Ultrasonography, Exercise
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ABBREVIATION LIST

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ACDF</td>
<td>Anterior cervical decompression and fusion</td>
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<tr>
<td>VAS</td>
<td>Visual analogue scale</td>
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<tr>
<td>NDI</td>
<td>Neck Disability Index</td>
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<td>RMS</td>
<td>Root mean square</td>
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INTRODUCTION

Persistent mechanical neck pain and disability is often reported by individuals who have previously undergone anterior cervical decompression and fusion (ACDF) surgery for cervical disc disease,\textsuperscript{1-6} despite an overall surgical success rate of about 80%.\textsuperscript{7, 8} Altered muscle function is a recognized feature of painful neck disorders,\textsuperscript{9, 10} and may be a factor in the persistent or recurrent nature of mechanical neck pain as cervical muscles have a significant role in the physical support of the cervical vertebral column.\textsuperscript{11} In turn, the presence of pain has been shown to have an immediate detrimental impact on cervical muscle function,\textsuperscript{12, 13} indicative of a pain-muscle dysfunction cycle in patients with mechanical neck pain. It is reasonable to expect that individuals who have longstanding persistent neck pain and disability following ACDF may also exhibit a compromised cervical muscle system. However, to date the motor function of this patient group has been largely understudied.

Initial studies investigating the voluntary contractile performance of the cervical muscles in ACDF patients have shown that compared to healthy controls, patients have between 47-79% of normal dorsal neck muscle strength\textsuperscript{1, 2} and 11-20% of normal cervical muscle endurance.\textsuperscript{1, 4, 6} While these studies have shown a reduced capacity for individuals to generate and sustain torque and endurance following ACDF, they do little to distinguish which muscles have deficits in contractile performance. For example the dorsal neck muscle group is comprised of five layers of muscles, each with some capacity to exert extensor moments to the cervical spine. Previous studies in non-surgical neck pain patients have shown altered behaviour within these dorsal neck muscle layers when performing resisted extension tasks.\textsuperscript{14} If the specific motor impairments underlying the observed deficits in cervical muscle contractile performance can be clarified in patients following ACDF, it would inform the design of rehabilitative exercise for their management.
The purpose of this pilot study was to undertake a preliminary comparison of the mechanical activity (deformation and deformation rate) of the multi-layered dorsal neck muscles during a resisted extension task, between a group of individuals who have, and have not, previously undergone an ACDF. Mechanical muscle activity in this study was recorded with an ultrasound method (speckle tracking). Our hypothesis was that differences in mechanical activity of the dorsal neck muscles would be evident between the two participant groups. This hypothesis was based on the significant impairments in contractile performance previously observed in this patient group compared to healthy individuals.\(^1\),\(^2\),\(^4\),\(^6\) It was anticipated that the findings of this study would provide feasibility data to underpin a future larger study to comprehensively investigate mechanisms underlying motor deficits in this patient group who commonly suffer longstanding pain and disability.

**METHODS**

**Participants**

Participants were recruited from a sample of convenience (individuals residing in close proximity to the city were the study was performed). Participants in the ACDF group were identified and recruited from a cohort of individuals that had participated in a previous randomized controlled study. Ten individuals (7 women and 3 men (mean age 60 years; SD, 7.1)) reporting residual pain ($\geq$10mm on the visual analogue scale (VAS)\(^ {15}\) and disability ($\geq$20% on the Neck Disability Index (NDI)\(^ {16}\) 10 years after ACDF for cervical disc disease participated in the study. These patients scored an average pain intensity of 36 mm (SD 24.9) on VAS and 31% (SD 8.9) on NDI. The comparison control group comprised ten healthy individuals matched to the patient group with respect to age and gender (mean age 60 years;
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SD, 6.5). Participants were excluded from the control group if they reported a history of neck or shoulder pain or injury, scored 10mm or greater on a VAS (mean VAS 0.08 (± 0.29)) when asked to rate their general level of neck discomfort,\textsuperscript{17} reported previous trauma to the neck or head, reported significant pain in the thorax or lower back, or reported any neurological or inflammatory conditions.

Ultrasound Measurements

Ultrasound recordings of the dorsal cervical muscle activity were made with a 14.0 MHz linear transducer (38 mm footprint) and an Ultrasound Vivid 9 dimension (GE Healthcare, Horten, Norway) unit utilizing a high frame rate (78 frames/s) operated in B-mode and a 2D ultrasound imaging system. Ultrasound images (ultrasound “video movie” of the dorsal neck muscles) of dorsal cervical muscle activity were recorded during the whole experimental resisted cervical dynamic extension task and later analyzed as image sequences (“video movies”) by post-process speckle tracking analysis.

The upper trapezius, splenius, semispinalis capitis and cervicis, and cervical multifidus muscles were recorded (Fig 1). All recordings were made at the C4 vertebral level identified by palpation of the C4 spinous process. To accurately locate the transducer, it was first positioned in a transverse orientation at the marked C4 level permitting identification of targeted muscle layers and bony landmarks. The transducer was then aligned longitudinally to the orientation of the dorsal muscles by rotating it 90° to ensure an optimal image plane for the post-process speckle tracking analysis.\textsuperscript{18} The transducer was located and maintained in position by one researcher during all testing procedures.
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Post-Process Speckle Tracking Analysis: In this method, a region of interest frame (10x2mm) was positioned over each of the muscles to be investigated in the first frame of the ultrasound video movie. Each region of interest frame thereafter contains an interference pattern of acoustic markers (speckle patterns) that is unique to the muscle it overlies. The region of interest frame is able to track its unique speckle pattern during the whole ultrasound video sequence (i.e. during the whole recorded dynamic neck extension motion (0° (neutral), to 20° cervical extension, to 0° (neutral)) and therefore track its deformation. In this manner the region of interest frame changes length in response to the longitudinal movement of the muscle speckle pattern during muscle contraction induced during the experimental extension task (Fig. 1). A speckle tracking algorithm (pattern scattering recognition) is utilized to calculate the median displacement value of all the speckles within the region of interest frame during the whole extension task recorded on ultrasound. For each muscle the first frame of the video sequences is recorded at rest immediately before the commencement of the extension effort. Deformation measurements calculated from this first frame are utilized as the reference value from which all deformation measurements from subsequent frames during the video are calculated. Two mechanical measurements of muscle activity are calculated from this process:

Muscle Deformation (% strain): This is defined as the momentary longitudinal change (frame by frame) in muscle tissue displacement (due to contraction) during the extension task relative to the resting reference length (recorded in the first frame). Muscle deformation during the extension task is expressed as a percentage of the resting muscle length (% strain).

Muscle Deformation Rate (% strain/sec): This is defined as the deformation per second (% strain/sec) representing the speed of muscle deformation during the extension task.
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These measurements have been shown to have moderate to excellent test-retest reliability for dorsal neck muscles (two-way random absolute agreement single measure Intra Class Correlation Coefficient 0.61-0.99) including measurement as performed in this current study (Intra Class Correlation Coefficient 0.71 to 0.97, with a standard error of the mean of 0.40 to 0.93 for muscle deformation, and 0.001 to 0.007 for muscle deformation rate).

**Experimental Procedure**

All participants performed the resisted cervical extension task in the DBC 140 dynamometer (David Back Clinic International, Karitie 9, Vantaa, Finland) (Fig. 2). Participants were positioned in the dynamometer so that they were seated with the spine in a neutral upright position (including the head and neck) at a height such that the back of the head rested on the dynamometer force application pad. A chest support was fitted tightly against the participant’s chest, their feet were flat on the floor, elbows in 90° of flexion, and they held onto the vertical columns of the machine.

All participants were first instructed by the investigator in the correct cervical extension maneuver while in the machine. They were instructed to push the back of their head against the resistance pad of the dynamometer so that the head and neck moved through a small range of extension (20° of extension from the upright posture as recorded by a goniometer inbuilt in the dynamometry machine) and then return to the starting position. This was performed against a standardized resistance provided by the dynamometer of 1kg for women and 2kg for men for a standardized duration (4 seconds in total) as indicated by a metronome. Instructions were given to the volunteers as follows, ‘I will count to three, and on three push your head against the head cushion and bend your neck gently backwards over a count of two seconds, and then return back to neutral over the count of 2 seconds. All participants were
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given 3 repetitions as a warm up and familiarization. Two repetitions of cervical extensions (5 minute rest between repetitions) were performed for data collection. During the experimental conditions, the researcher recorded the ultrasound imaging and saved the recorded image sequences (“videos”) for post-processing speckle tracking analysis and calculation of the deformation and deformation rate measurements. A separate video was recorded for each of the two repetitions. Participants were instructed to cease the testing procedure if they experienced any onset of neck symptoms.

Data Management and Statistical Analysis

Measurements of muscle deformation and deformation rate were calculated from the ultrasound video sequences of the experimental extension task. All values were expressed as root mean square (RMS) over the duration of the task. The RMS values are based on the curve of the changes in deformation and deformation rate in the longitudinal ultrasound projection over the entire extension task for each repetition. The average of the measures recorded for the two experimental extension repetitions was used for analysis.

Analyses were performed using a statistical package (SPSS version 20: IBM). On the basis that most data were normally distributed and the variance was equal across groups (Levene’s test of equality of error variances), a repeated measures general linear model was used to evaluate main effects for group (ACDF, control), and group x muscle interactions. A Bonferroni correction was used for multiple comparisons of the deformation and deformation rate measurements. Post-hoc tests of simple effects were performed when indicated. Statistical significance was accepted at the 0.05 alpha level.
RESULTS

Data for the measures of deformation and deformation rate in the ACDF and healthy control groups for all muscles are shown in Table 1.

Deformation: There was a significant group x muscle interaction (p < 0.03) but no main effect of group (p = 0.26) for the measure of muscle deformation. Exploratory tests of simple effects revealed that only the deformation measure for the semispinalis capitis muscle was significantly different between groups (p < 0.03; mean (SD) for ACDF 3.12(2.06) and controls 6.64(4.17), mean difference 3.34 (95%CI -0.54 to 7.21)) with the ACDF group showing significantly less deformation during the extension task compared to the controls (Table 1).

Deformation rate: There was no significant group x muscle interactions (p > 0.79) or main effects of group (p > 0.91) for the measure of muscle deformation rate (Table 1).

DISCUSSION

This pilot study provides preliminary evidence of altered mechanical activity of the dorsal neck muscles in patients with longstanding pain and disability following an ACDF. Specifically, compared to the control group, the participants in the ACDF group demonstrated reduced deformation of the semispinalis capitis muscle during the resisted cervical extension task. The semispinalis capitis is the largest of the extensor muscles within the dorsal muscle group and is therefore capable of exerting large extensor moments to the head and neck. Therefore, this finding may be relevant to previous reports of reduced cervical extensor strength and endurance\(^1\),\(^2\),\(^4\),\(^6\) in this patient group. A reduced contribution by this important extensor muscle
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may also contribute to functional difficulties often reported by these patients during activities that load the extensor muscles such as prolonged antigravity activities (eg. reading with the neck in flexion). However, the findings of this study are relatively modest and should be regarded as preliminary. Group differences were only observed in one out of the five dorsal muscles examined for the measurement of deformation, and no differences were noted for the deformation rate measurement in any of the muscles. Notwithstanding this, these preliminary findings do warrant a more rigorous exploration of the impairments underlying the motor deficits in these patients with persistent symptoms following ACDF surgery.

The findings of this study are also consistent with previous reports of altered extensor muscle activity during resisted neck extension tasks in patients with non-surgical related mechanical neck pain.\textsuperscript{20, 21} However, as opposed to these previous studies, reduced activity was not found in the deeper dorsal muscle layers (semispinalis cervicis, multifidus) in response to the extension task in this current study. Differences in findings between this and the previous study may also reflect factors such as the different patient populations studied (surgical versus non-surgical), as well as differences in measurements used (electromyography,\textsuperscript{21} magnetic resonance imaging (MRI)\textsuperscript{20}). In addition, in both the study of O’Leary et al.\textsuperscript{20} and Schomacher et al.,\textsuperscript{21} participants performed an isometric extension task in contrast to the isotonic extension task performed in this current study. Furthermore, there were some differences in the magnitude of resistance applied during the extension task between these previous studies (20% maximal voluntary contraction,\textsuperscript{20} 15 and 30N,\textsuperscript{21}) and the current study (1 kg women, 2 kg men), although all could be considered relatively low load resistance. While collectively these studies reflect a disturbance in cervical motor function in individuals with persistent mechanical neck symptoms, discrepancies between studies highlight the need for further scientific investigation and clarification of motor disorders in the neck extensor muscles in neck pain. Notwithstanding this, the results of this study support the
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recommendations of previous studies showing deficits in cervical extensor muscle strength and endurance in patients who have undergone ACDF, for the inclusion of exercise in the total post-operative management of these patients.

Study Limitations and Future Recommendations

There are limitations to this study. The sample size utilised in this study was small and participants were recruited from a sample of convenience, however we matched the groups to improve the power of the group comparisons. Prior to the commencement of this study no similar published studies from which sample size could be calculated were available. Using data from this study to retrospectively evaluate sample size we estimate that to reach 80% power, a sample size of 14 participants would have been required to detect group differences in semispinalis capitis muscle deformation, suggesting that our findings are feasible for this muscle. In contrast a sample size of 63-527 individuals would have been required to detect differences in the other muscles evaluated mainly due to large measurement variance for these muscles. These findings of large measurement variance are consistent with previous studies reporting muscle movement patterning to be highly individual. Also all participants undertook a standardized resisted cervical extension task which potentially may not have represented an equal challenge to the dorsal muscles of all participants. The motor response to a range of load intensities will need to be examined in this patient group in the future. However a relatively low load was used in this first study to ensure the task was not provocative of neck pain which may have confounded the motor measures. Furthermore the ultrasound measurement used in this study may have limitations. The 2D ultrasound method and speckle tracking analysis used was only able to register longitudinal muscle deformation during muscle contraction of dynamic extension. Any rotational components of muscle motion were thereby not captured. Individual anatomical architecture and position could not
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be accounted for and muscles may be in slightly different planes during recordings which may impact the deformation results of each muscle.

While there is initial evidence of a relationship between voluntary muscle contraction and the muscle deformation measure\(^2\) this new measurement method of muscle activity is still being refined in terms of clinical and research utility. In particular, the measurements of muscle deformation (and deformation rate) were performed over a specific region of interest within each muscle and may not provide an overall activity level representation of all regions of the muscles.

CONCLUSIONS

In this study ultrasound measurements of muscle deformation and deformation rate of the dorsal cervical muscles during a resisted cervical extension task were compared between participants with long-term pain and disability following ACDF, and healthy controls. The only finding of significance was of a reduced deformation of the semispinalis capitis muscle in the ACDF group compared to the control group during the task. This may be of relevance to previously observed deficits in the strength of the dorsal neck muscles of this patient group on the basis of the substantial extensor torque producing capacity of the semispinalis capitis muscle. Findings also lend support to previous recommendations for the inclusion of exercise to train neck muscle performance within the management plan of these patients.

ETHICAL APPROVAL
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This study received approval from the Regional Medical Research Ethics Committee and was conducted in accordance with the declaration of Helsinki. All participants received verbal and written information about the study and signed a consent form.

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CONFLICT OF INTEREST

We hereby declare that there is no conflict of interest.
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REFERENCES


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