Further evaluation of an EMG technique for assessment of the deep cervical flexor muscles

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Abstract

A novel surface electromyographic (EMG) technique was recently described for the detection of deep cervical flexor muscle activity. Further investigation of this technique is warranted to ensure EMG activity from neighbouring muscles is not markedly influencing the signals recorded. This study compared deep cervical flexor (DCF) muscle activity with the activity of surrounding neck and jaw muscles during various anatomical movements of the neck and jaw in 10 volunteer subjects. DCF EMG activity was recorded with custom electrodes inserted via the nose and fixed by suction to the posterior mucosa of the oropharynx. Surface electrodes were placed over the sternocleidomastoid, anterior scalene, masseter and suprahyoid muscles. Positioned in supine, subjects performed isometric cranio-cervical flexion, cervical flexion, right and left cervical rotation, jaw clench and resisted jaw opening. Across all movements examined, EMG amplitude of the DCF muscles was greatest during neck movements that would require activity of the DCF muscles, particularly during cranio-cervical flexion, their primary anatomical action. The actions of jaw clench and resisted jaw opening demonstrated significantly less DCF EMG activity than the cranio-cervical flexion action (p < 0.05). Across all other movements, the neighbouring neck and jaw muscles demonstrated greatest EMG amplitude during their respective primary anatomical actions, which occurred in the absence of increased EMG amplitude recorded from the DCF muscles. The finding of substantial EMG activity of the DCF muscles only during neck actions that would require their activity, particularly cranio-cervical flexion, and not during actions involving the jaw, provide further assurance that the majority of myoelectric signals detected from the nasopharyngeal electrode are from the DCF muscles.

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1. Introduction

In recent years our research has been orientated towards identifying and quantifying deficits in the deep cervical flexor (DCF) muscles, longus colli and longus capitis, in patients with neck pain disorders. This has been in recognition of the DCF muscles essential role in support of the cervical motion segments [21,33] and the cervical lordosis [2,27,26], as well as the indirect evidence of impairment in these muscles in neck pain patients [15,17,16,32]. Furthermore, specific therapeutic retraining of the DCF muscles has demonstrated efficacy in the management of patients with chronic neck pain and cervicogenic headache [18]. Consequently assessment and rehabilitation of the DCF muscle group is considered important in the management of cervical spine disorders [19].

Whilst there had been some evidence of impairment in the DCF muscles from histological studies [29], direct electromyographic analysis of these muscles was limited. Several decades ago, an intra-muscular fine wire EMG technique using an approach similar to cervical discography procedures was used to study the action of the longus colli muscle at the C5/6 vertebral level in healthy individuals [10,31]. However, no such EMG technique has been reported for the assessment of the DCF muscles in neck
pain sufferers. In fact, there had been no subsequent report of fine wire EMG studies of the DCF muscles in humans, due at least in part to the risks associated with invasive techniques to the anterior cervical spine such as those reported for cervical discography [3,11,12,23,25,34]. The DCF muscles are located deep to proximal respiratory, gastrointestinal, vascular, lymphatic and neural structures of the anterior neck. These structures could be vulnerable to puncture during the insertion of fine wire electrodes, or susceptible to infection with any deposit of blood on withdrawal of the fine wires. These structures also make the DCF muscles not accessible to traditional surface EMG techniques.

More recently, we proposed an alternative EMG technique for the assessment of the DCF muscles [5]. This technique involves a nasopharyngeal application to position electrodes over the posterior oropharyngeal wall at the level of the C2/3 intervertebral disc, directly overlying the longus colli and longus capitis muscles. In the original report of this EMG technique we evaluated the electrodes’ ability to measure activity of the DCF muscles by detecting EMG signals during progressive stages of the cranio-cervical flexion test (CCFT) in healthy participants with no history of neck pain. The CCFT involves progressive graded inner range positions of cranio-cervical flexion performed in supine with the head rested on the supporting surface [17]. This CCFT action combines flexion of the cranio-cervical junction, the primary anatomical action of longus capitis, with a flattening effect of the cervical lordosis, an anatomical action of the longus colli muscles, and is thus considered a specific test of the DCF muscles. EMG signals recorded from the new method supported the anatomical predictions of the CCFT by revealing a strong positive linear relationship between the normalized EMG amplitude for the DCF muscles, and progressively inner range positions of the CCFT [5].

Subsequent studies using this EMG technique have investigated the activation of the DCF muscles in people with chronic neck pain disorders [6,7]. Results have demonstrated that when compared to healthy individuals, neck pain sufferers have decreased DCF EMG activity when performing the CCFT [7], as well as delayed activation of the DCF muscles in response to rapid arm movements in standing [6]. The findings from these studies indicates altered voluntary and automatic function of the DCF muscles, and is suggestive of an impaired capacity of the DCF muscles to support the cervical spine in individuals with neck pain.

The location of the electrode and the small inter-electrode distance incorporated in the electrode design, as well as the strong positive correlation between the myoelectric signals detected and the progressive stages of the CCFT suggests that the majority of the signals detected with this electrode are from the DCF muscles [5]. Furthermore, examination of the within-day and between-day repeatability of root mean square values from the DCF EMG, has revealed normalised standard error of the mean values in the range of 6.7–10.3% which provides evidence of repeatability in terms of the techniques repeated measure precision [5]. Nonetheless, further evaluation of this technique is necessary to ensure activation of nearby muscles, such as the superficial cervical flexor and jaw muscles, does not largely contribute to the signal recorded.

The most direct method of assessing unwanted signals from muscles lying in the vicinity of the muscle of interest (myoelectric crosstalk), is to examine signals detected at different sites while selectively stimulating a single muscle. In practice, this would be extremely difficult in the neck and jaw region. An alternative technique for the detection of crosstalk, has been to examine the cross-correlation of surface EMG signals detected above different muscles during voluntary muscle contractions. However, recent studies have concluded that cross-correlation analysis is not a valid measure for quantifying crosstalk or distinguishing between crosstalk and coactivation during voluntary contractions [8,24]. In order to investigate whether neighbouring neck and jaw muscles were largely affecting the signal recorded from the nasopharyngeal electrode positioned over the DCF muscles, we selected to examine patterns of muscle activation during various anatomical movements of the neck and jaw. If the majority of signals detected from the nasopharyngeal electrode were representative of DCF muscle activity, we would expect to identify increases in EMG amplitude principally during the anatomical actions that would require DCF muscle activity (cranio-cervical flexion, cervical flexion, cervical rotation). Furthermore, we would expect to detect low EMG amplitude from the other neck and jaw muscles during the cranio-cervical flexion task when compared to their amplitudes during the tests biased towards their individual primary anatomical action.

The purpose of this study was to compare the activity of the DCF muscles and neighbouring neck and jaw muscles during a series of isometric contractions of the neck and jaw to determine whether the signal recorded with the nasopharyngeal electrode was consistent with the anatomical actions of the DCF muscles.

2. Methods

2.1. Subjects

Fourteen female volunteers (aged 36.1 ± 15.6 yrs, mean ± SD) participated in the study. Subjects were included if they were free of neck and jaw pain at the time of testing, had no past history of orthopaedic disorders and had no history of neurological disorders. Subject’s were screened in accordance with contraindications and precautions for the use of Xylocaine spray local anesthetic [28] and the procedure of nasopharyngeal suctioning [13]. Ethical approval for the study was granted by the Institutional Medical Research Ethics Committee. All studies were conducted in accordance with the declaration of Helsinki and subjects provided written informed consent.
2.2. Electromyography

EMG recordings of the left DCF muscles were made using custom made electrodes [5]. The apparatus consisted of bipolar silver wire electrode contacts (dimensions: 2 mm × 0.6 mm, inter-electrode distance: 10 mm) attached to a suction catheter (size 10FG), with a heat sealed distal end, which were inserted via the nose to the posterior oropharyngeal wall. The electrode was fixed to the mucosa with suction pressure of 30 mmHg via a portal between the two electrode contacts and by placement of the electrode at the level of the uvula (approximately the level of the C2–3 intervertebral disc) which is the level at which the longus colli muscle has its greatest cross-sectional area [22] (Fig. 1). Location of the electrode was confirmed by inspection through the mouth. Placement of the electrodes ensured correct orientation along the fibres of the DCF muscles, approximately 1 cm lateral to the midline. Once this position was achieved, suction was applied to maintain electrode–mucosa contact. Prior to insertion, the nose and pharynx were anaesthetised with three metered doses of Xylocaine® spray (Astra Pharmaceuticals, Sweden) administered via the nostril and three metered doses to the posterior oropharyngeal wall on the same side, via the mouth.

Recordings of EMG activity from the sternal head of sternocleidomastoid (SCM), anterior scalene (AS), suprahyoid (SH) and masseter (MS) muscles were made with Ag/AgCl surface electrodes (11 mm disc electrode, inter-electrode distance: 11 mm) (Grass Telefactor, Astro-Med Inc.) following careful skin preparation. Electrodes were positioned along the line of the SCM and AS muscles bilaterally in the distal 1/3 of the muscle belly [4]. For the MS muscle the belly was palpated during jaw clenching and the electrodes were fixed parallel to the fibers 2.5 cm above the mandibular angle on the left side [14]. For the SH muscles, electrodes were positioned midway between the inferior tip of the mandible and the thyroid cartilage on the left side. The ground electrode was placed on the upper thoracic spine. EMG data were amplified (Gain = 1000), band pass filtered between 20 Hz and 1 kHz and sampled at 2 kHz. Data were sampled with Spike software (Cambridge Electronic Design, Cambridge, UK) and converted into a format suitable for signal processing with Matlab software (The MathWorks, Inc. Natick, MA, USA).

2.3. Procedure

The subjects were positioned in supine, and performed a series of isometric neck and jaw muscle contractions in a randomised order. The muscle tests consisted of cranio-cervical flexion, cervical flexion, left and right cervical rotation, jaw clench and jaw open. For the test of cranio-cervical flexion, subjects performed a gentle nodding action to reach full cranio-cervical flexion range of motion without lifting their head off the bed. For the test of cervical flexion, subjects were asked to lift their head so that it just cleared the bed and was held isometrically. Left and right cervical rotation were performed isometrically in the neutral position against a moderate resistance applied by an investigator to the lateral aspect of the head, posterior to the orbit. For the task of jaw clench, subjects were asked to clench their teeth together at a moderate intensity, whilst for the test of jaw open, subjects performed an isometric

![Fig. 1. Cross-sectional area of the upper cervical spine at the level of the 2nd cervical vertebrae: The deep cervical flexor muscles, longus colli and longus capitis lie directly behind the posterior oropharyngeal wall. Electrode contacts attached to a suction catheter are positioned on the posterior oropharyngeal wall using a nasopharyngeal application.](image-url)
contraction against a moderate intensity resistance applied by an investigator to the under surface of the mandible. Each contraction was sustained isometrically for 10 s. Manual resistance was applied consistently by one investigator across all subjects. Subjects were asked not to swallow during each contraction to avoid activity from the pharyngeal constrictor muscles.

2.4. Data management and statistics

Due to the difficulty in normalising EMG amplitude for the muscles of interest, EMG amplitude was expressed in absolute form. To obtain a measure of EMG signal amplitude, maximum RMS was calculated for 1 s for each muscle using Matlab software (The MathWorks, Inc. Natick, MA, USA). Reporting the data as absolute EMG amplitude precludes a between-muscle comparison for the different tasks due to the various factors which influence EMG amplitude (electrode location, thickness of the subcutaneous tissues, distribution of motor unit conduction velocities among others [9]). For this reason, EMG amplitude for each muscle was compared across the different tasks.

Although there may be variation in the intensity of each muscle contraction, the tasks were specific to the muscles investigated. Therefore, to identify whether the EMG amplitude from neighbouring neck and jaw muscles was largely influencing the signals detected from the nasopharyngeal electrode overlying the DCF muscles, we examined patterns of muscle activation during various anatomical movements. If the signal detected from the nasopharyngeal electrode was largely due to activation of the DCF muscles, then we would expect to identify greatest EMG amplitude recorded from this electrode only during cranio-cervical flexion, the anatomical action of the DCF muscles. Furthermore, we would then expect to detect low EMG amplitude from the other muscles (AS, SCM, MS, SH) during the cranio-cervical flexion task when compared to their amplitudes during the tests biased towards their individual primary anatomical action.

The EMG data did not conform to a normal distribution (skewed to the right) therefore log transformations were used prior to statistical analysis. A repeated measures analysis was performed on the logged EMG data with task as the within subject factor. Post hoc comparisons were performed to compare the EMG amplitude means of each muscle across all tasks. All statistical analyses were performed using SPSS 10.0 for Windows. A value of \( p < 0.05 \) was used as an indicator of statistical significance.

3. Results

When subjects performed a series of neck and jaw isometric contractions, greatest EMG amplitude of the DCF muscles was detected during the muscle actions involving the neck, and in particular during the DCF muscles primary anatomical action of cranio-cervical flexion. Fig. 2 depicts the DCF EMG amplitudes across all tasks and the significant differences between DCF muscle EMG amplitude when performing the cranio-cervical flexion action compared to the jaw opening and jaw closing tasks \((p < 0.05)\).

Data for the SCM, AS, MS and SH muscles are presented in Fig. 3. For the SCM muscles, significantly greater EMG amplitude was identified for cervical flexion compared to all other tasks \((p < 0.01)\). EMG amplitude was greater for contralateral cervical rotation compared to ipsilateral rotation for both the left and right SCM muscles \((p < 0.01)\). For the left SCM greater EMG amplitude was present during cranio-cervical flexion, jaw open and contralateral cervical rotation compared to jaw clench \((p < 0.05)\). For the right SCM greater EMG amplitude was present during cranio-cervical flexion and contralateral cervical rotation compared to jaw clench \((p < 0.05)\). The AS muscles demonstrated greatest EMG amplitude for cervical flexion compared to all other tasks \((p < 0.05)\) and greater activation during cranio-cervical flexion compared with jaw clench \((p < 0.05)\). For the left AS muscle greater EMG activity was identified during jaw open compared to jaw clench \((p < 0.05)\).

The MS muscle demonstrated greater EMG amplitude in the jaw clench task compared to cranio-cervical flexion, jaw open and left and right cervical rotation \((p < 0.05)\). Furthermore, greater EMG amplitude was present for the MS muscle during cervical flexion compared to cranio-cervical flexion \((p < 0.05)\). The SH muscles demonstrated greatest activation during cervical flexion \((p < 0.05)\) followed by jaw open. Fig. 4 illustrates representative electromyographic activity for the DCF, MS, SH and left AS and SCM muscles across all tasks.

4. Discussion

The results of this study confirm that the greatest EMG amplitude detected with the nasopharyngeal electrode
Fig. 3. Data for superficial neck and jaw muscle EMG amplitude during neck and jaw movements: Root mean square values (mean and standard deviation) for the masseter (MS), suprahyoid (SH) muscles and the left (L) and right (R) sternocleidomastoid (SCM) and anterior scalene (AS) muscles obtained during cervical flexion (CF), cranio-cervical flexion (CCF), jaw clench (JC), jaw open (JO), and right and left cervical rotation (ROT). Horizontal lines denote significant differences (p < 0.05).

Fig. 4. Representative EMG activity recorded during neck and jaw movements: Raw EMG data for the deep cervical flexors (DCF), masseter (MS), suprahyoid (SH) and left (L) anterior scalene (AS) and sternocleidomastoid (SCM) muscles. Data from one subject are shown during the tasks of cervical flexion (CF), cranio-cervical flexion (CCF), jaw clench (JC), jaw open (JO), right (R) and left cervical rotation (ROT).
occurred during the action of cranio-cervical flexion (Fig. 2). During the other isometric contractions, notable increases in EMG amplitude were present only for the actions that would also require DCF muscle activity (cervical flexion, cervical rotation) and not for actions where anatomically there would not be an expectation of DCF activity (jaw movements).

These findings support our notion that the greatest amplitude of myoelectric signals detected from the nasopharyngeal electrode is derived from the DCF muscles, the primary muscles producing the cranio-cervical flexion action. In support of this notion was the finding of relatively low EMG amplitudes from the other muscles (AS, SCM, MS, SH) during the cranio-cervical flexion task when compared to their amplitudes during the tests biased towards their individual primary anatomical action (Fig. 3). Therefore, these results support the proposition that the nasopharyngeal electrode positioned directly over the DCF muscles is not largely influenced by an increase in EMG activity from surrounding neck and jaw muscles.

Not surprisingly, DCF muscle EMG amplitude for the action of cervical flexion was also substantial, and although apparently less than for the cranio-cervical flexion action, this was not statistically significant. DCF EMG activity was also detected for cervical rotation bilaterally. The slight supero-medial orientation of the DCF muscles at the C2/3 vertebral level (the position of the electrode) would suggest that these muscles may contribute more to ipsilateral rotation of the upper cervical motion segments than contralateral rotation but there appeared to be no difference between the direction of rotation relative to electrode placement. Vitti and colleagues [31], using their fine wire EMG technique, described a contralateral rotation action of the longus colli muscle however their recordings were made at the C5/6 vertebral level where the orientation of some longus colli muscle fibres are supero-lateral and would tend to exert some contralateral rotation moments. The increase in EMG amplitude found for the DCF muscles for cervical rotation bilaterally may reflect the stability role of these deep muscles during movements other than their primary anatomical action.

As expected the SCM muscles demonstrated the most EMG amplitude during the action of cervical flexion, followed by the action of contralateral cervical rotation. The SCM muscle spans the entire anterolateral cervical spine attaching the manubrium and medial clavicle to the mastoid process of the temporal bone and the superior nuchal line of the occipital bone [20]. Unilateral contraction of the SCM muscle produces contralateral rotation of the cranium and cervical spine, which is consistent with the data recorded in this study. Contracting bilaterally from a neutral cervical spine position, SCM is a flexor of the lower cervical spine and an extensor of the upper cervical spine, particularly the posterior portions of the muscle [30]. The anterior portions of SCM (sterno-occipital and cleidooccipital) have relatively neutral moment arms about the cranio-cervical articulations in neutral head and cervical spine postures [20]. In line with this, the data demonstrated significantly less EMG amplitude for the SCM muscle in the task of cranio-cervical flexion which supports the clinical test of CCF [7,19] to differentiate activation between the DCF and SCM muscles.

The AS muscles also demonstrated greatest EMG amplitude during the action of cervical flexion. These muscles arise from the scalene tubercle of the first rib and attach to the C3–6 transverse processes [20]. Contracting bilaterally, the AS muscles flex the middle and lower cervical spine region [30]. Despite no attachment to the cranium, the AS muscles also demonstrated some activity during the action of cranio-cervical flexion. This may reflect the common attachment of the superior portion of the AS muscle, and the inferior portion of the longus capitis, and longus colli (superior oblique portion) muscles, to the C3–6 transverse processes. During the cranio-cervical flexor action the anterior scalene muscle may assist in anchoring the inferior attachment of the longus capitis and colli muscles, as well as assisting in the flattening effect of the cervical lordosis. Although the scalene muscles have previously been found to contribute to ipsilateral rotation of the cervical spine when contracting unilaterally [1], no significant difference was identified between ipsilateral and contralateral rotation for the AS muscles in this study.

The SH muscle group have attachments from the mandible to the hyoid bone that elevate and retract the hyoid bone, and depress the mandible (jaw opening). The infrahyoid muscles attach the hyoid bone to the thorax and consequently when the mandible is kept closed, the combined contraction of both SH and infrahyoid muscles will pull the mandible towards the sternum, inducing a flexor moment at all cervical motion segments. This is evident when observing the SH EMG amplitude during the cervical flexion action and to a much lesser degree during the cranio-cervical flexion action. EMG amplitudes for the SH muscles during the cervical flexion action were found to be even greater than during their primary action of jaw opening which most likely reflects the different load requirements of the tasks.

As expected the MS muscle demonstrated greatest EMG amplitude during the primary anatomical action of jaw clenching. Some activity was noted during the cervical flexion action which most probably reflects the maintenance of a jaw clenched position such that the combined hyoid muscle group can assist in flexion of the cervical spine.

4.1. Methodological considerations associated with the technique of DCF EMG detection

The nasopharyngeal EMG technique for detection of DCF EMG activity has now been successfully applied
in multiple investigations [5–7]. The procedure has been well tolerated by all subjects and no side effects associated with the technique or anaesthetic have been reported. However, some inherent limitations associated with the procedure still exist and must be considered when using this technique. This includes a restricted length of testing due to the limited duration of the anaesthetic (<15 min) and the requirement that an investigator stand to the side of the subject and hold the catheter in place throughout testing. Although this may give the subjects additional cues and influence movement, it is unlikely to explain the differences which have been identified between people with neck pain and controls in our previous studies using this technique [6,7]. A further limitation of the technique is the inability to identify the innervation zone prior to electrode placement. Estimation of EMG signal amplitude and spectral variables are subject to electrode location relative to the innervation zone prior to electrode placement. Estimation of the technique is the inability to identify the innervation zone from the surface EMG. J Appl Physiol 2004;96:1486–95.

5. Conclusion

The results of this study indicate that the greatest EMG amplitude detected with the nasopharyngeal electrode is derived from the DCF muscles. This data supports the continued use of this technique for the evaluation of function and dysfunction of the deep cervical flexor muscles.

References


Deborah Falla received her PhD from The University of Queensland, Australia in 2003. In 2005 she was awarded fellowships from the International Association for the Study of Pain and the National Health and Medical Research Council of Australia to undertake postdoctoral research at the Center for Sensory-Motor Interaction, Aalborg University, Denmark. Her research focus involves the integration of neurophysiological and clinical research to evaluate the patho-physiology underlying muscle impairment in people with neck pain. Her research interests also include investigation of the physiological mechanisms that underpin the efficacy of therapeutic exercise for the treatment of patients with neck pain.

Gwendolen Jull is Professor and Head of the Division of Physiotherapy in the School of Health and Rehabilitation Sciences at The University of Queensland, Australia. She is a Consultant Musculoskeletal Physiotherapist and leads the Cervical Spine and Whiplash Research Unit at The University of Queensland. Her research and clinical interests are in understanding the patho-physiology of neck pain in terms of the sensory, motor and psychological features of both idiopathic and whiplash induced neck pain as a basis for diagnosis, treatment and prevention of recurrence cervical musculoskeletal disorders. The research is also concerned with testing the efficacy of specific exercise programs for the management of neck pain as well as investigating the physiological mechanisms of effect of therapeutic exercise for the cervico-brachial region.

Shaun O’Leary graduated with a Bachelor of Physiotherapy in 1993, and a Masters in Manipulative Physiotherapy in 2000, from The University of Queensland, where he has since completed his doctoral degree. Shaun’s doctoral thesis investigated the effectiveness of dynamometry in the measurement of cervical muscle performance. Shaun presently continues clinical practice as a musculoskeletal Physiotherapist in Brisbane, Australia, and research within the Physiotherapy Division at The University of Queensland. His research focus is in the functional and clinical anatomy of the cervical spine, and the development of assessment and rehabilitation methods for the management of cervical spine disorders.

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