The use of functional MRI to evaluate cervical flexor activity during different cervical flexion exercises

Running head: MRI and cervical flexor activity

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Abstract

The purpose of this study was to investigate the recruitment pattern of deep and superficial neck flexors evoked by three different cervical flexion exercises using muscle functional MRI.

In 19 healthy participants, T2 values were calculated for the longus colli (Lco), longus capitis (Lca) and sternocleidomastoid (SCM) at rest and following three exercises: conventional cervical flexion (CF), craniocervical flexion (CCF) and a combined craniocervical flexion and cervical flexion (CCF-CF).

CCF-CF gave the highest T2 increase for all muscles. CCF displayed a significantly higher T2 increase for the Lca compared to the Lco and the SCM. When comparing the CCF and CF, no significant difference was found for the Lca, whereas the Lco and SCM displayed a higher T2 increase during CF compared to CCF.

This study shows that muscle functional MRI can be used to characterize the specific activation levels and recruitment patterns of the superficial and deep neck flexors during different cervical flexion exercises. During CCF-CF, all synergists are maximally recruited, which makes this exercise useful for high-load training. CCF may provide a more specific method to assess and retrain Lca muscle performance, compared to CF and CCF-CF. This study highlights the need to differentiate between the Lco and Lca when evaluating their function, since these results demonstrate a clear difference in activation of both muscles.

Keywords: MRI, cervical flexion exercise, neck flexors
Introduction

Neck disorders are a common and costly problem in society, affecting approximately 70% of people at some point in their life (7; 36). Evidence has shown that exercises to improve the performance of the cervical spine muscles are effective to alleviate chronic neck pain (12; 21; 29; 37). With regard to the cervical flexors, there is mounting evidence of an association between chronic neck pain and impaired cervical flexor muscle performance (10; 14; 15; 28). Therefore, assessment and retraining for their performance is advocated in clinical practice (28).

Conventional flexion (CF) and craniocervical flexion (CCF) are two basic methods that have been described in research and clinical literature to assess and retrain the cervical flexor muscles (3; 12; 18; 20; 21; 30; 35; 37). During CF the subjects’ head and neck are flexed together on the thorax, whereas during CCF the head is flexed on the cervical spine (22; 24; 27; 29; 34). Few studies are available investigating the difference in cervical flexor muscle performance between these tests and these studies are solely based on EMG measurements (12; 27). EMG has demonstrated that both CF and CCF muscle contraction methods elicit similar EMG activation of the deep cervical flexors (DCF) [longus capitis (Lca) and longus colli (Lco)]. Interesting to note is that in all previous studies, Lco and Lca are investigated as one entity, although according to the difference in their anatomical action (the primary anatomical action of Lca is flexion of the craniocervical junction; the primary action of Lco is flattening of the cervical lordosis), it seems worthwhile to investigate the recruitment patterns of both muscles separately (11-13; 15; 22; 34).

Compared to a CCF method, CF additionally elicit substantial activation of superficial cervical flexor muscles (SCM, and anterior scalene) (27). The manner in which CF methods are performed, differs depending on the study. In the study of O’Leary et al. participants were instructed to maintain a neutral craniocervical orientation while performing CF (27). In other studies utilising conventional CF methods, subjects were instructed to initiate the test by tucking their chin in first before commencing CF (32; 33). At present, there is no consensus as to the best method of training cervical flexor muscle performance. Therefore, it should be interesting to investigate the different patterns of cervical flexor muscle activation during the performance of 1) a CCF, 2) a pure CF and 3) a combined exercise (CCF-CF).
However, definitive conclusions about cervical muscle function is difficult with EMG due to technical limitations, such as the inability to provide an indication of specific muscle patterns, variability in the myoelectric signal attributed to subcutaneous tissue and electrode type and placement, and confounding of the myoelectric signal by cross talk among muscles (23). Secondly, it is not possible to reach the DCF with surface EMG. Nevertheless, Falla et al. described a novel surface EMG technique for the detection of DCF muscle activity. However, this technique is not useful in clinical practice and it is still not possible to infer if this method can test the DCF in isolation (13; 27).

Magnetic resonance imaging (MRI) has the potential to provide a more reliable and objective assessment of cervical muscle function than surface EMG (23). Muscle functional MRI is an innovative technique that enables investigation of the activity pattern of muscles. The method relies on an acute activity-induced increase in transverse relaxation time (T2) of muscle water (1; 16; 17). This increase in T2 causes an enhancement in signal intensity of activated muscles (31). Despite its widespread use for evaluation of skeletal muscle and soft tissue elsewhere in the body, the use of muscle functional MRI for the cervical muscles has been limited. Only Conley et al. evaluated the neck muscle function evoked by different head movements. However, they only evaluated CF with the emphasis on the larger muscles (5; 6). In order to confirm or refute the results of the previous EMG studies, it should be interesting to define the activity pattern of the neck flexor muscles with muscle functional MRI.

Therefore, the purpose of this study was to investigate the recruitment pattern of the Lco, Lca and SCM evoked by three different cervical flexion exercises (CF, CCF and CCF-CF) using muscle functional MRI.
Materials and methods

Subjects
Nineteen healthy subjects (10 men and 9 women) with a mean age of 22.2 ± 0.6 years, participated in the study. Exclusion criteria were recent neck pain, back pain or headache from cervical origin (< 3 months) and contra-indications to MRI (a cardiac pacemaker, claustrophobia, implanted metals, unremovable piercings, aneurysm clips, carotid artery vascular clamp, neurostimulator, cochlear or ear implants, and (possible) pregnancy within the first 3 months). The project was approved by the local ethics committees. Written informed consent was obtained from all subjects.

Exercise protocol
Three exercises were performed in a fixed order: 1) CCF-CF, 2) CF, and 3) CCF. For all three exercises, patients were positioned in supine with only the weight of the head as resistance. For each exercise, subjects executed an isometric hold to fatigue performed three times with one minute of rest between the sets. The mean time each exercise was performed was 89.6 ± 35.6 seconds (CCF-CF), 69.8 ± 31.1 seconds (CF) and 107.72 ± 50.0 seconds (CCF). There was 45 minutes of rest between the different exercises. The half-life of exercise-induced changes in muscle T2 has been shown to be 7 minutes (16). According to Conley, a rest period of 45 minutes is required which allows approximately 98% of the T2 shifts to be recovered (5).

CCF-CF: The CCF-CF is a combination of a CF and a CCF, in which subjects are instructed to initiate the movement by CCF first before commencing CF (figure 1a).

CF: For CF, subjects were asked to lift their head so that it just cleared the supporting surface and was held isometrically. They were instructed that during CF, they were neither to tuck their chin in nor let their chin protrude so as to keep the craniocervical motion segments neutral (figure 1b).

CCF: For CCF, a pressure cuff was used (Stabilizer; Chattanooga Group Inc.), which was placed suboccipitally behind the subject's cervical spine and inflated until a stable pressure of 20 mmHg was achieved. The pressure sensor is used as a biofeedback to monitor the slight flattening of the cervical lordosis and register the muscular effort and associated small movement of the cervical spine as an
increase in pressure. Prior to the test day, subjects were instructed to perform a gentle nodding action until full craniocervical flexion range of motion was reached. The pressure level that the subject could achieve and hold in a steady manner for 10 x 10 seconds with the SCM relaxed and without lifting the head off the surface was determined. During the exercise, participants were asked to accurately maintain this level of contraction effort until fatigue prevented them from sustaining the contraction any longer (figure 1c). Participants were instructed to discontinue the test when they perceived an inability to sustain the contraction at the indicated intensity.

Subjects were familiarized with each of the movements prior to the test day. The CF and CCF-CF were performed in the scanner, whereas the CCF was performed outside the scanning room, as a pressure cuff was used, which is partially constructed of metal.

**MRI**

MRI was performed on a 3 Tesla magnet (Siemens Magnetom 'Trio a Tim System' with Syngo MR B13). A flexible surface coil, 20 x 50 cm, fixed over the anterior aspect of the participant's neck was combined with the phased-array spine coil as a receiver coil combination. The subjects were placed in a comfortable and relaxed supine position, with their hips flexed to 45° and legs supported by foam wedges. The head was positioned in a neutral position, without rotation, lateral flexion or exaggerated lordosis. Axial images of the cervical spine were obtained at rest and immediately after each exercise.

A sagittal localizing sequence was performed every time the subject re-entered the magnet to ensure a similar cervical position in the magnet bore between repeated images. Axial images of the cervical spine were obtained from the C1 to the C6 segmental level and were positioned parallel to the C2-C3 intervertebral disk, which served as a point of reference. There were 5 transaxial slices, 5-mm-thick with 10 mm space between each slice, including one at the C2-C3 interspace and two slices above and two slices below this point. For T2 calculation, a multi-spin echo sequence was used: repetition time of 2500 milliseconds; echo times 10 to 161.6 milliseconds with steps of 10.1 milliseconds (16 echos), field of view 256 mm, matrix 128 x 128 and voxel size 2x2x5mm. Total acquisition time was 5:12 minutes. Imaging procedures were identical for the resting scan and the three scans after exercise.
Data management

After scanning, the images were transferred to a computer for calculation of muscle T2 using ImageJ, a Java-based version of the public domain NIH Image software (Research Services Branch, National Institutes of Health). Regions of interest (ROI) were identified on the T2 images: on the base of its clearest visualisation, the Lca was analyzed on the first slice whereas the SCM and Lco were analyzed on the fourth slice (figure 2). The T2 value of the semispinalis cervicis and multifidus, were calculated in 5 subjects at rest in order to serve as a control value.

When defining a ROI, nonmuscular tissue within the ROI, such as fat, fascia, and vessels, was avoided. Calibrated LaCie screens were used to accurately define the ROI. Sixteen echos were used in T2 calculation using a Simplex algorithm to fit the values from the specific slice in a T2 image volume to the exponential $S_n = S_0 \exp(-TEn/T2)$ ($n=1:16$). The mean T2 value and its standard deviation was derived for each ROI. Inter-rater reliability of T2 measurements was calculated for the Lca, Lco and SCM on the same images (72 measures) by three different researchers.

Statistical analysis

Analysis was performed using the SPSS statistical software (version 12).

For analysis of inter-rater reliability, intra-class correlation coefficients (ICC) (Two-Way Mixed Effect Model - Absolute Agreement) with 95% confidence intervals, standard error of measurement (SEM) and smallest real difference (SED) were used. Defined with respect to a 95% level of confidence, the smallest real difference is equal to $1.96 \sqrt{2*SEM}$.

Descriptive statistics (mean and standard deviation) were calculated for T2 values (millisecond) at rest and after exercise for each muscle group. T2 increase values, which are defined as the difference between T2 values at rest and after exercise, were used for statistical analysis. T2 increase was evaluated using analysis of variance with repeated measures. Factors for T2 shift were exercise (CCF, CF and CCF-CF), muscle group (Lca, Lco and SCM), and side of body (left and right). Because there were no significant interactions involving side of the body with exercise ($p=0.362$) and muscle group ($p=0.433$), the values of the right and left sides were averaged for further analyses.
Post hoc comparisons were made when required and LSD adjustments were used to correct for multiple tests. Statistical significance was accepted at the 0.05 alpha level.
Results

Inter-rater reliability

The intraclass correlation coefficients for the inter-rater agreement of the T2 measures ranged from 0.87 to 0.94 depending on the muscles evaluated, indicating excellent reliability (table 1).

Muscle T2 at rest

There were no significant differences in the resting T2 values between the Lca (44.1ms ± 3.3), Lco (44.5ms ± 2.8) and the SCM (43.6ms ± 3.4) (p>0.05). The resting T2 value of the semispinalis cervicis and multifidus, which served as a control value, was found to be 43.7 ms ± 3.3.

Muscle T2 increase following exercise

Mean T2 increase values plotted by muscle group and exercise are shown in figure 3. In the overall statistical model for T2 increase, there were significant exercise (p<0.001) and muscle group (p<0.001) main effects, and a significant exercise by muscle group interaction (p=0.002).

Compared with rest, all three muscles displayed a significant T2 increase with each exercise (p<0.05).

During CCF-CF, the SCM showed a significantly lower T2 increase than Lco (p=0.008) and Lca (p=0.009), while during CCF the Lca demonstrated a significantly higher T2 increase than the SCM (p=0.010) and Lco (p=0.037). During CF, there was no significant difference in T2 increase between the three muscles.

For the Lca, the T2 increase during CCF-CF was significantly higher than during CF (p=0.002) and CCF (p<0.001). For the Lco and SCM, the T2 increase during CCF was significantly lower than during CF and CCF-CF (p<0.001).
Discussion

The results of this study show that muscle functional MRI can be used to characterize the specific activation levels and recruitment patterns of the superficial and deep cervical flexors during different exercises.

Before interpreting the results, two remarks have to be considered.

The first remark is that although the Lco and Lca may show a similar or higher relative use, the SCM probably makes a greater contribution than the Lca and Lco because of its larger size (about 6.0cm² versus 1.5cm²) (5).

Secondly, higher T2 values were found compared to previous studies (2; 5; 17; 25). The most acceptable reason for this discrepancy is the fact that different imaging sequences were used, which may have given a systematic deviation of 10 to 20%. Other reasons may be that subjects were not asked to rest before the acquisition took place, as was done in the study of Mayer et al., or that non-muscular tissue was taken up when defining the ROI (23). However, these arguments can be refuted. The subjects in the study of Conley et al. also did not have a rest moment before the scanning and still they got lower values. It is suggested that it is more important to insert a rest moment while testing the lumbar muscles compared to the cervical muscles. The fact that non-muscular tissue was taken up when defining the ROI can also be rejected as it was possible to isolate muscular tissue in the SCM and comparable higher T2 values were found.

Different exercises

CCF

The Lca displayed a significant higher T2 increase than the Lco and SCM. In previous literature, it is speculated and demonstrated that the CCF method is more specific to the anatomical action of the DCF muscles, and less specific to the anatomical action of the superficial cervical flexors (13; 27). In these studies, however, the Lca and Lco were lumped together as the DCF and no difference was made between both muscles (5; 11; 28).
This study indicates that it could be useful and even necessary to distinguish between both muscles which may not be surprising. The primary anatomical action of Lca is flexion of the craniocervical junction, whereas the primary action of Lco is flattening of the cervical lordosis (13). The results suggest that during the CCF the craniocervical flexion action requires more activity than the flattening of the cervical lordosis or that the Lca assists in the flattening of the lordosis, implying that this activity is spread among both muscles.

However, as will be discussed in the limitations of the study, the Lco and Lca were investigated at different levels, to clearly distinguish between both muscles. It can not be ruled out that a difference in activity can be due to the difference in level.

**CF**

The T2 increase for the Lco for the action of CF was substantial, and although apparently higher than for the Lca and SCM, this was not statistically significant. Previous studies did not compare the DCF and the SCM during the performance of CF, however, one could assume from their results that no significant differences between these muscles were found (5; 13; 27). Falla et al. and Conley et al. found a higher activity of the DCF, whereas O'Leary et al. found a lower activity of the DCF compared to SCM (5; 13; 27). Differences in intensity of the exercise or methods to reach CF may explain this discrepancy.

**CCF-CF**

The T2-increase for the Lco and Lca was significantly greater than that of the SCM. This may be surprising, but as previously mentioned, this does not mean that the DCF are predominantly active. The moment generating capacity depends amongst others on the CSA of the muscle and its moment arm. According to Vasavada et al. the sternocleidomastoid has the largest flexion moment arm (34). During the CCF-CF, the head flexion is about 10%, which corresponds with a moment arm of up to 2-3 cm, whereas the Lca and Lco display a much smaller moment arm (0.5-1 cm) (34). So, due to the higher CSA and higher moment arm of the SCM, it seems plausible that this muscle attributed more to the movement.
Comparing the different exercises

When comparing the CCF and CF, no significant difference was found for the Lca, whereas the Lco and SCM displayed a higher T2 increase during CF compared to CCF. Falla et al. as well as O’leary et al. compared the activity of the different muscles between CF and CCF (13; 27). Both authors found no significant difference for the DCF between CF and CCF, whereas SCM showed higher activation during CF than CCF. The latter is in accordance with our results, however the former result should be questioned. The fact that no difference was found for the DCF between CF and CCF, whereas our results found a higher activity for the Lco, but not for the Lca during CF, supports our proposition that the Lco and Lca should be investigated separately.

When comparing the CCF-CF and CF, no difference in activity for the Lco and SCM was seen. On the other hand, the Lca showed a higher T2 increase during the combined movement compared to CF. This means that the surplus value of the combined movement in comparison with the conventional CF method, is the higher activation of the Lca.

Clinical implications

The results of this study reflect some important implications for rehabilitation strategies. A rehabilitation program normally consists of two types of exercise programs. The first exercise regime consists of general strengthening and endurance exercises for the neck flexor muscles. These exercises involve high load training and thus recruit all the muscle synergists that is, both the deep and superficial muscles. In this study, CCF-CF gave the highest change in T2 increase for all muscles. So, all synergists are maximally recruited, which makes this exercise very useful for high-load training in order to increase general strength and endurance (3; 4; 8; 12; 18; 37).

The second exercise regime has been designed to focus on the muscle control aspects and aims at improving control of the muscles within the neck flexor synergy (9; 19; 26; 29). In contrast to more traditional high load strength and endurance exercises, low load exercise is used to train the coordination between the deep and superficial neck muscles. In this study, the CCF has been shown to be a good exercise to specifically train the Lca. In contrast, the Lco, which is also a deep neck muscle, has been shown to be less activated during this exercise. This is a new fact, as in previous literature, both Lca an
Lco were always lumped together. These findings support the fact that the Lco is not the prime mover of the CCF action, but rather a synergist.

Limitations of the study

The present results must be viewed within the limitations of the study.

CCF was performed outside the scanning room, whereas the CF and CCF-CF were performed in the scanner. However, the time between the end of the exercise and the scanning lasted only 1.5 minutes, which may have little consequences as the half-life time of exercise-induced changes in muscle T2 has been shown to be 7 minutes (16).

Another potential limitation of the study is that exercise was presented in sequential order, rather than a random presentation. Although it is likely that T2 recovered between exercise bouts, it is possible that there was residual fatigue in the cervical flexors that may have confounded muscle recruitment and perceived exertion. Future research is needed to evaluate the effect of exercise order on the T2 response and time course of T2 recovery following exercise.

Movement artefacts due to respiration and pulsed streaming of the blood made the determination of the ROI not that easy. This was especially the case for the Lco which is closely related to the trachea. However, good reliability was found (ICC=0.89). In addition, it was not possible to localise the AS, as this was influenced by the pulsations of the carotid artery. The results of this muscle would have been of interest as this is also an important flexor of the cervical spine. In previous EMG studies, this muscle was also investigated in which it was found that, although this muscle had no attachment to the cranium, it showed some activity during the action of the CCF (13; 27).

As previously mentioned, the Lco and SCM were investigated at the same level, whereas the Lca was investigated at a higher level. Differences in T2 increase between the different muscles could be attributed to the different levels of investigation.
Further research

It would be interesting to evaluate the same muscles at different cervical levels to investigate if there are variations in activity within a muscle depending on the level. It would also be interesting to evaluate the activity pattern of other muscles, such as the AS and the cervical extensors.

Future research is needed in individuals with a history of neck pain and muscle impairment to establish the influence of symptoms on muscle activation when performing these exercises.

Conclusion

This study showed that muscle functional MRI can be used to characterize the specific activation levels and recruitment patterns of the superficial and deep cervical flexors during different cervical flexion exercises. CCF-CF gave the highest change in T2 increase for all muscles. All synergists are maximally recruited, which makes this exercise useful for high-load training. CCF may provide a more specific method to assess and retrain Lca muscle performance, compared to CF and CCF-CF. This study highlights the need to differentiate between the Lco and Lca when evaluating their function, since these results demonstrate a clear difference in activation of both muscles.

Grants

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Acknowledgements

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### Tables

Table 1: Intraclass correlation coefficients (ICC), standard error of measurement (SEM) and smallest detectable difference (SDD) for inter-rater reliability. 95% confidence interval (95% CI)

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<th>ICC (95% CI)</th>
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Figure legends

Figure 1: The three exercises used: A, combined cervical flexion – craniocervical flexion (CF-CCF); B, cervical flexion (CF); C, craniocervical flexion (CCF).

Figure 2: Region of interest of the Longus capitis identified on the first slice.

Figure 3: Increased relaxation times (means ± standard deviation) of Lca, Lco and SCM after CF-CCF, CF and CCF. Asterisks indicate statistically significant differences (p<0.05).
Reference List


figure 1b
389x340mm (96 x 96 DPI)
figure 1c
389x340mm (96 x 96 DPI)
**figure 2**
60x68mm (72 x 72 DPI)