MRI analysis of muscle/fat index of the superficial and deep neck muscles in an asymptomatic cohort

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Abstract All muscles of the neck have a role in motion and postural control of the cervical region. The aim of this study was to investigate the difference in muscle/fat index between (1) cervical flexors and extensors and (2) deep and superficial neck muscles. Twenty-six healthy subjects participated in the study. Magnetic resonance imaging (MRI) was used to quantify muscle fat indices in different cervical flexor and extensor muscles at the C4–C5 level. Overall, the ventral muscles had a significantly lower fat content compared with the dorsal muscles ($P \leq 0.001$). For the cervical extensors, significant differences between the muscle/fat index of the deep and superficial muscles were found ($P \leq 0.001$). For the cervical flexors, there were no significant differences between the different muscles. The higher fat content in the dorsal muscles can be explained by a discrepancy in function between the spine extensors and flexors, reflected in a different muscle fiber distribution. The rather small differences between superficial and deep neck muscles are in line with recent findings that have demonstrated that both muscles groups exhibit phasic activity during isometric muscles contractions and the presumption that there is no difference in fiber type distribution between superficial and deep neck muscles.

Keywords MRI · Cervical · Muscle · Fat

Introduction

The primary function of the cervical spine is to orientate the head against the opposing forces of gravity whilst permitting multi-directional tasks [2, 21, 22]. All muscles of the neck have a role in motion and postural control of the cervical region; however, the varying locations, attachments, lever arms, and fiber composition of individual muscles define their primary function. A functional division has been made between muscles [1, 6, 24]. Deep and superficial axial muscles are thought to have different roles in stabilizing the spine and producing force or movement in humans. Based on their small moment arms and their attachments to adjacent vertebrae, the deep axial muscles are believed to stabilize the spine. With their large-moment arms and attachments to the skull and trunk, the more superficial muscles are believed to be predominantly prime movers.

Magnetic resonance imaging (MRI) continues to be widely used as a diagnostic modality in the evaluation of muscles. As it has been demonstrated that deposition of fat shows a high-signal intensity on MRI, Elliott et al. established a simple method to quantify muscle/fat constituents in cervical extensor muscles [11, 16, 18]. Although it is not possible with MRI to determine absolute concentration of fat, the intensity of the signal provides a reliable indication of the amount of fat in the muscle. Elliott et al. has demonstrated a significantly greater fatty infiltration in the neck extensor muscles, especially in the deeper muscles in the upper cervical spine, in subjects with persistent whiplash associated disorders (WAD), but not in patients with persistent insidious-onset neck pain [9, 10].

Although the muscle/fat indices in the cervical extensors have been extensively investigated by Elliot et al., little is known about the cervical flexors, which have been

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demonstrated to be dysfunctional in chronic neck pain patients [9–11, 13–15, 23].

Therefore, the aim of the present study was to investigate the muscle/fat index in both superficial and deeper cervical flexors and extensors and to compare this index between (1) cervical flexors and extensors and (2) deep and superficial neck muscles.

Materials and methods

Subjects

Twenty-six healthy subjects (9 men and 17 women) with a mean age of 31.4 ± 8.3 years, participated in the study. All subjects were right-handed. 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.

MRI

Magnetic resonance imaging was performed on a 3 T magnet (Siemens Magnetom 'Trio a Tim System' with Syngo MR B13). A flexible surface coil, 20×50 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. A sagittal localizing sequence was first performed to identify cervical disc space intervals. six axial images with a slice thickness of 5 mm were obtained from the C1 to the C7 segmental level, ensuring proper capture of the paraspinal musculature. The axial MR slices were positioned parallel to the consecutive intervertebral discs.

For the determination of the muscle/fat index, T1-weighted images were obtained using the following imaging sequences: Field of view read: 200 mm; relaxation time: 550 ms; echo time: 9 ms; flip angle 1: 75° and flip angle 2: 120° ; acquisition time: 3:35 seconds.

Data analyses

For the determination of the muscle/fat index, the procedure as described by Elliott et al. [9, 11] was followed.

All muscles were investigated at the same level (C4–C5), to rule out the influence of segmental level. Both deep and superficial muscles at the dorsal and ventral side were investigated. Deep cervical flexors were the longus capitis (Lca) and the longus colli (LC), superficial cervical flexor was the sternocleidomastoideus (SCM). Superficial cervical extensors were the trapezius (TR), levator scapula (LS) and splenius capitis (SCa) and the deep cervical extensors were semispinalis cervicis (SCe) and multifidus (MU) (Fig. 1).

A measure of relative fat within muscle was created by developing a pixel intensity profile with free DicomWorks software. The region of interest (ROI) was traced over each of the bilateral muscles. Histograms were then created from the summated user-defined ROI, displaying each particular muscular pixel intensity profile. Subsequently, a user-defined ROI consisting of an area of intermuscular fat was also created at the C2 vertebral level. Careful attention was taken to ensure the fat ROI consisted only of an area of high-signal intensity, which invariably produced a population of voxels with higher pixel intensities on the fat histogram.

An index of fat within the muscle was then created from the pixel intensity summary. The measure, which was developed, consisted of the pixel intensities for each muscle ratioed to the standardized region of intermuscular fat. The reliability of the MRI measure was performed on six randomly selected patients (total of 48 muscles) on the

Fig. 1 Cervical muscles used in analyses on the C4–C5 level: sternocleidomastoideus (SCM), longus capitis (Lca), the longus colli (LC), trapezius (TR), levator scapula (LS) splenius capitis (SCa) semispinalis cervicis (SCe) and multifidus (MU)

right side by three different investigators. The ICC values for intertester reliability were 0.91, indicating a high level of repeatability.

Statistical analyses

All statistical analyses were performed using SPSS 15.0 for windows. All data are presented as mean $\pm$ standard deviation (SD). The normality of variables was evaluated by the Kolmogorov–Smirnov test, which demonstrated a normal distribution ($P > 0.05$).

A general linear model was used to investigate within group differences in muscle/fat index for the factors muscle and side of the body (left and right). Post hoc comparisons were made and least significant differences adjustments were used to correct for multiple tests. Statistical significance was accepted at the 0.05 alpha level.

Results

In the overall statistical model, there were significant muscle/fat index main effects for muscle ($F = 115.89$, $P < 0.001$) and side ($F = 59.80$, $P < 0.001$), and significant interactions between muscle and side ($F = 31.82$, $P < 0.001$). The difference between sides was of a mean of $6.7 \pm 3.4\%$, which was consistently lower on the right side compared to the left side.

Although the difference between sides reached statistical significance, the sides were averaged to compare between muscles. Mean muscle/fat indices plotted by muscle group are shown in Table 1 and Fig. 2.

Overall, the cervical flexors [Lca (0.30 ± 0.07), LC (0.31 ± 0.07), SCM (0.31 ± 0.06)] had significantly lower fat content compared with the cervical extensors [Tr (0.53 ± 0.07), LS (0.49 ± 0.08), SCa (0.47 ± 0.06), SCe (0.45 ± 0.07) and MU (0.45 ± 0.06); $P \leq 0.001$].

For the cervical extensors, there were no differences between SCe and MU ($P = 0.202$) and between LS and SCa ($P = 0.231$). The muscle/fat index of the SCe and MU

Fig. 2 Magnetic resonance imaging muscle/fat indices for the cervical musculature. Data presented are means $\pm$ SD

were significantly lower than that of the Tr, LS and SCa (all $P \leq 0.001$). The Tr showed significantly higher fat content than the LS and SCa (all $P \leq 0.001$). For the cervical flexors, there were no significant differences between Lco, Lca and SCM ($P = 0.940$).

Discussion

The present study sought to use MRI to provide further information concerning the muscle/fat ratio of different neck muscles. The technique used to detect the relative fat content in muscle has been developed by Elliott et al. and is based on the principle that signals on T1-weighted images are very sensitive to the presence of fatty deposition in muscle [11]. This technique has been found reliable with a good to excellent intra- and inter-rater agreement, which is in accordance with the reliability values we found [11].

Higher muscle fat indices were found compared to previous studies. The most acceptable reason for this discrepancy may be the supposition that intermuscular fat was not determined in exactly the same way as Elliot et al. did. However, for the present study, this has little consequences as no comparisons between individuals were done.

Significant differences between the left and right side were found in all muscles. The difference between sides was of a mean of $6.7 \pm 3.4\%$, which was consistently lower on the right side compared to the left side. Differences between sides could probably be explained by dexterity, as all subjects were right handed. However, to

Table 1 Mean ($\pm$ SD) muscle/fat indices for the cervical musculature

	Mean	SD
Longus colli	0.31	0.07
Longus capitis	0.30	0.07
Sternocleidomastoid	0.31	0.06
Semispinalis cervicis	0.45	0.07
Multifidus	0.45	0.06
Levator scapulae	0.49	0.08
Splenius capitis	0.47	0.06
Trapezius	0.53	0.07

confirm this assumption, measurements should be repeated on left handed subjects.

Specific patterns of muscle/fat indices were identified throughout the cervical muscles on both the left and right side. The present results support our first hypothesis that there is a significant difference in muscle/fat index between cervical flexors and extensors. The muscle/fat indices of the dorsal muscles were quite higher than these of the ventral muscles. The difference in fat content can be explained by a discrepancy in function between the spine extensors and flexors due to a dynamic imbalance of the cervical spine, which is also reflected in a difference in muscle strength between both muscle groups. Mean extension/flexion ratio has been shown to be around 1.5 [5, 25]. The larger extension strength over flexion by 50% reflects the postural role of extensor musculature which may be explained by the fact that the center of gravity of the head during activity, such as reading, is often located in front of the axis of rotation, leading to higher postural demands on the neck extensor muscles. This difference in function is reflected in the difference in muscle fiber distribution. Uhlig et al. demonstrated in neck pain patients that the muscle fiber distribution of the posterior muscles contained relatively more type I fibers than the anterior muscles [29]. The discrepancy in fiber type distribution between dorsal and ventral muscles has also been demonstrated by Boyd-Clark et al. [4]. They demonstrated that the LC comprises an even type I/type II fiber ratio and can therefore respond equally to postural and phasic demands, whereas MU is predominantly type I in character (4:1) reflecting its postural function in resisting cervical flexion [4].

Muscle fiber distribution plays an important role in the degree of lipid concentration. It is well documented that skeletal muscles enriched in type I fibers were shown to have a greater capacity for fatty acid metabolism (uptake, oxidation and storage) than muscles with a greater proportion of type II fibers [7, 8, 19]. The higher lipid content in type I fibers compared to type II fibers may represent differences across muscle fiber types in heparin releasable lipoprotein lipase activity and in plasma membrane fatty-acid binding protein content, both being higher in type I compared to type II muscle fibers [3]. These are factors directly involved in the processes of fatty acid entrance into muscle, and accordingly could be plausible reasons for the muscle fiber-type specific difference in lipid content.

The second hypothesis stated that there was a significant difference between superficial and deep neck muscles. However, in the present study, no differences between the superficial and deep neck muscles at the ventral side were found. Although the superficial muscles at the dorsal side had a significantly higher muscle/fat index compared to the deep cervical extensors, only small dissimilarities

occurred, except for the UT. This observation contradicts our initial hypothesis that the deep neck muscles would have a greater muscle/fat index compared to the more superficial neck muscles. This was expected as the deep and superficial axial muscles are thought to have different roles in stabilizing the spine and producing force or movement.

However, as previously mentioned, differences in function would be reflected in a different muscle fiber type distribution. One could assume that stabilizing muscles may exhibit a predominance of type I fibers compared to the more superficial muscles. The bulk of available spinal literature has concentrated on the lumbar and thoracic spine, due in part to the incidence of low back pain and idiopathic scoliosis. Studies on the lumbar paraspinal muscles have shown that there is no significant difference between the fiber type characteristics of the MU and the more laterally situated longissimus and iliocostalis muscles, despite their different anatomical position [20, 26–28]. To the best of our knowledge, no studies are available investigating the difference in fiber type distribution between deep and superficial neck muscles. Further work in this field is mandatory.

Secondly, a recent study has questioned the functional division into stabilizing and mobilizing muscles [2]. The results of the study of Blouin et al. demonstrated that all neck muscles can exhibit phasic activity during isometric neck muscle contractions and conclude that these results do not support the fact that the deeper neck muscle layers receive descending neural control signals independent from the superficial neck muscles [2].

So, although our initial hypothesis could be rejected, our results are in line with (1) the supposition that there is no difference in fiber type distribution between superficial and deep neck muscles and (2) recent findings that both muscles groups exhibit phasic activity during isometric muscles contractions.

The UT showed significantly higher fat content than all other muscles. Because the UT is generally classified as a shoulder muscle and is innervated by the accessory nerve, a different pattern of muscle fat distribution compared with actual neck muscles is perhaps not surprising [2].

The present results must be viewed within the limitations of the study. The muscle/fat index was only investigated at the C4–C5 level. This level was chosen as this is the level which act as the pivot through which movements of the head and neck are mediated. It would be interesting to investigate the muscle/fat index of each muscle at the different levels. Elliott et al. found a cephalad to caudad decline in fat content in all muscles [9]. In the lower back, greater dependence on type I fibers with rostral muscle position is thought to be related to larger flexion moments and anterior displacement of rotational axes in

the thoracic spine [4]. This comparison can be extrapolated to the cervical spine, where the upper part has also larger flexion moments and anterior displacement of rotational axes compared to the mid and lower cervical spine.

As it is not possible with MRI to determine absolute concentration of fat, the method of analyzing differences in signal intensity as an indication of the amount of fat in the muscle was chosen. This method has demonstrated to be reliable but has never been confirmed by muscle biopsy [11]. It is possible that other factors, such as blood flow, may also influence the differences in signal intensity. In order to demonstrate the accuracy of this technique, it is recommended to more exactly investigate the underlying mechanisms of alterations in MR signal intensity and to validate this method by muscle biopsy.

Clinical implications

Identifying variations in the muscle morphometry across an asymptomatic population provides the basis for future cross-sectional investigations examining MRI signal intensity changes in the musculature and their potential relationship to neck pain. As previously mentioned, Elliott et al. have demonstrated a significant increase in fatty infiltration in the deep cervical extensor muscles in subjects with persistent WAD [9]. As there is mounting evidence of an association between chronic neck pain and impaired cervical flexor muscle performance, and as research has demonstrated that specific therapeutic retraining of the deep cervical flexor muscles is efficient in the management of patients with chronic neck pain and cervicogenic headache, examining MRI signal intensity changes in the cervical flexor musculature in neck pain patients is indicated [9–12, 15, 17].

Little is known about the muscle fiber type distribution in cervical muscles. Although it is indicated to validate this technique by muscle biopsy or spectroscopy, this simple method seems promising as a non invasive and indirect technique to evaluate muscle fiber type distribution of deep muscle tissue in vivo.

Conclusion

The muscle/fat indices of the dorsal muscles were quite higher than these of the ventral muscles, which can be explained by a discrepancy in function between the spine extensors and flexors, reflected in a different muscle fiber distribution. Only little differences were found between the deep and superficial neck muscles. This is in line with previous studies that have demonstrated that both muscles groups exhibit phasic activity during isometric muscles

contractions and the presumption that there is no difference in fiber type distribution between superficial and deep neck muscles.

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