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ORIGINAL REPORT

WHIPLASH INJURY RESULTS IN SUSTAINED IMPAIRMENTS OF CERVICAL MUSCLE FUNCTION: A ONE-YEAR PROSPECTIVE, CONTROLLED STUDY

Søren KROGH, MSc[1] and Helge KASCH, MD, PhD[1,2]
From the [1]Spinal Cord Injury Centre of Western Denmark, Viborg Regional Hospital, Viborg, and [2]Department of Clinical Medicine, Aarhus University Hospital, Aarhus, Denmark

Objective: **To investigate the temporal development of neck muscle function following whiplash injuries.**
Design: **A 1-year prospective, controlled observational study.**
Subjects: **A total of 141 individuals exposed to whiplash injury due to rear-end vehicle collisions and 40 age- and sex-matched controls with acute ankle distortion.**
Methods: **Neck muscle strength and endurance during cervical flexion and extension were measured at 1 week, 1 month, 3 months, 6 months and 1 year after injury.**
Results: **Notable reductions (23–30%) of neck strength in both directions were seen for whiplash-exposed subjects at all time points, compared with controls. Also, extensor endurance was reduced at 1 week, 1 month, 3 months, 6 months* and 1 year* (*non-significant). Within the whiplash group, non-recovered individuals (individuals who had not returned to pre-injury work capacity at one year) displayed ~50% reductions in cervical strength in both directions at all time points, compared with recovered whiplash individuals.**
Conclusion: **Cervical muscular functioning is impaired for at least one year after whiplash injury, well beyond the time course of recovery of neck mobility and pain sensations. In whiplash-exposed individuals, non-recovery is associated with considerable muscular weakness. There is a need for increased clinical focus on early neck function after whiplash injury.**

Key words: whiplash injuries; neck muscles; muscle strength; rehabilitation.

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Correspondence address: Helge Kasch, Spinal Cord Injury Centre of Western Denmark, Viborg Regional Hospital, DK-8800 Viborg, Denmark. E-mail: helgkasc@rm.dk

MAIN MESSAGE

Whiplash injuries from car accidents can result in long-term disabilities in the individual, with resulting considerable societal costs. The after-effects of whiplash injury have been investigated extensively, but not much is known about the long-term effect of these injuries on neck muscle functioning, or the role that neck muscle function plays in the process of recovery after whiplash injuries. This paper provides evidence that: (*i*) some areas of neck muscle function are affected for at least one year after the injury; and (*ii*) whiplash-exposed individuals who recover (are able to return within one year to pre-injury work routines) present with much better neck muscle function than those who do not. The paper also discusses the importance of neck muscle function in rehabilitation after injury.

Despite improvements in car safety, such as seatbelts and headrests, whiplash injuries after motor vehicle collisions persist as significant personal and societal burdens. These sudden extensions and hyperflexions of the neck can lead to a complex array of clinical manifestations, such as neck pain and stiffness, headache, motor disturbances and psychosocial symptoms (1, 2). Half of those exposed to whiplash injuries will still report symptoms years after the injury and more than 20% will still not be considered recovered after 5 years (3).

Cervical muscle strength (CS) and endurance (CE) may be important aspects of neck disorders, as they have been shown to be reduced by ~15–50% in patients with general, idiopathic neck pain without traumatic onset (4–7) and to inversely correlate with pain scores and disability during rehabilitation (8, 9). However, the role of CS and CE after whiplash injuries remains largely uninvestigated; in fact, only a few studies have examined this subject. Prushansky and colleagues (10) tested CS in 97 subjects with whiplash-associated disorders (WADs) grade II/III, and compared their results with published data on healthy individuals. They reported that neck strength in their group of patients was reduced by 80% and 90% in women and men, respectively. In another study, Descarreux et al. (11) found mean reductions of ~35% and ~26% in cervical flexion and extension strength, respectively, in another group of patients with WADs (n=17). This was accompanied by a significantly prolonged mean time to peak force compared with healthy controls (329 vs 271 ms). Finally, Peolsson et al. (12) carried out a cross-sectional study on the CE of individuals with chronic WADs and healthy controls. Here the authors reported that the former had 22–83% reductions in CE across the sexes and direction of movement, compared with the latter.

Furthermore, electromyography (EMG) studies have demonstrated that a proportion of individuals who experience after-effects of whiplash injuries have abnormal

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muscle activation patterns (13–16), perhaps as a protective mechanism to minimize the use of painful muscles.

However, across the limited literature on cervical strength and endurance after whiplash, there are considerable differences in subjects and methods. For example, in subjects, assessment-time from injury varies from 6 to 132 months, and different units for force measurements are employed. In addition, no data on the temporal development of CS after whiplash injuries are available, and the preceding use of healthy controls may allow for bias.

The aim of this study was therefore to investigate the development of isometric CS and CE in a whiplash-injured population at specific time points after the injury. A group of sex- and age-matched subjects with acute ankle distortion (AD) and similar initial global pain levels served as controls. This design was chosen so that the mere stress associated with pain and acute injury was present in both groups, and these possibly confounding factors would be controlled. Members of our team have previously demonstrated that active cervical range of motion (CROM) is inhibited immediately after a whiplash trauma, but that it has recovered at 3 months post-injury (17); here, long-term non-recovery correlated strongly with initial reduction of active CROM (18). We hypothesized that complications after whiplash injury would result in decreased CS and CE in the acute phase, but that these parameters would recover in a time course similar to CROM.

METHODS

Study design

The present study was carried out as part of a larger project on complications following whiplash injury. Other results from the project have been published elsewhere (1, 17, 19, 20), and cover areas such as headache, neck pain and mobility, work capacity and pain perception.

In short, patients were first seen approximately one week after injury, and then returned for similar examinations at 1, 3, 6 and 12 months after injury. Patients with whiplash (Whip) group: during the course of one year whiplash-exposed persons seen in the emergency units covering the former county of Aarhus, Denmark area (covering 284,000 inhabitants at the time) were invited to participate. Inclusion criteria were: (*i*) whiplash due to rear-end vehicle collision; (*ii*) preservation of consciousness during collision; (*iii*) no direct head trauma or sign of amnesia after the injury; (*iv*) contact with the local emergency unit within 2 days after collision presenting whiplash injury-related complaints, such as neck pain or headache; and (*v*) age between 18 and 70 years. Exclusion criteria were: previous considerable neck or back disorders or severe head injuries, severe headache, migraine, or widespread pain, or a record of severe psychiatric disease along with known medical or alcohol abuse. A total of 141 whiplash-exposed subjects were included at baseline. For a schematic overview of the exclusion process, see Fig. 1.

Control group (AD); 141 persons sustaining acute non-sport ankle distortion, where X-ray had ruled out fracture, were seen at the Emergency Units at 2 Departments of Orthopaedic Surgery, Aarhus University Hospital. A total of 101 patients were non-responders or were excluded under the same criteria as the whiplash-exposed subjects, leaving 40 age- and sex-matched (21 females; 19 males) subjects to serve as controls.

Recovery status: whether or not the individual had returned to pre-injury work routines (return-to-work status) was chosen as the factor of recovery in the present study. However, many other indices are used across the literature and in clinical practice.

This study was approved by a local ethics review board (Aarhus County Ethical Committee #1996/3799) and it conformed to the Declaration of Helsinki.

Neck muscle assessment

A neck-trainer instrument (Neck Exercise Unit, Follo Futura, Norway) with a computerized device for measuring maximal torque (Nm) was applied to examine isometric neck muscle strength during extension (at 15° extension) and flexion (at 30° flexion) (see Fig. 2). These angles were chosen due to signs of obvious distress in pilot whiplash-exposed subjects when extending beyond this range of motion. The equipment has previously been validated (21), showing acceptable intra-day and day-to-day variation. First, the subject was restrained to the chair with a strap across the chest, to avoid trunk movement.

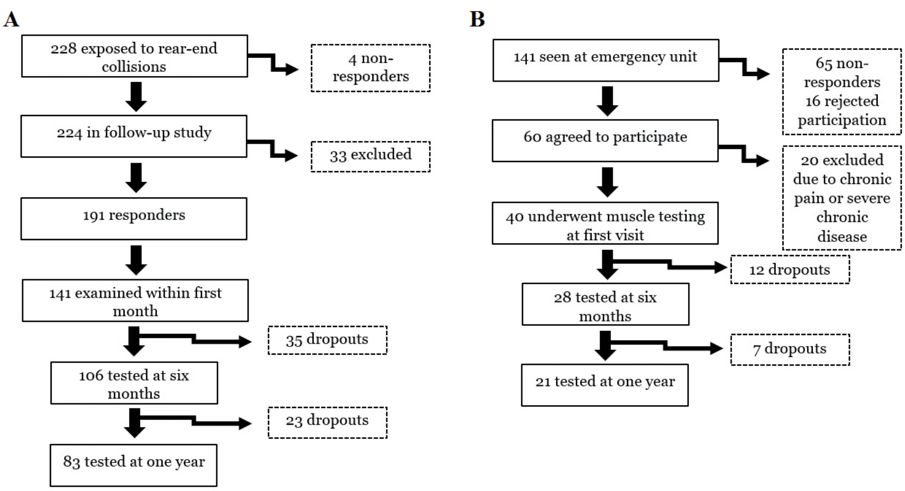

Fig. 1. (A) Flowchart of the exclusion process of whiplash-exposed subjects. A total of 228 subjects were exposed to rear-end collision; 33 were excluded due to: chronic low back pain (12); chronic neck pain or whiplash sequelae (7); widespread pain (3); severe chronic disease (7); unconsciousness during accident (3); non-compliance at first visit (1). At 1-year follow-up, 74 of the 83 (89%) participants were regarded as clinically recovered. (B) A flowchart of the exclusion process of the control group with ankle distortions. A considerable number of drop-outs are present in both groups.

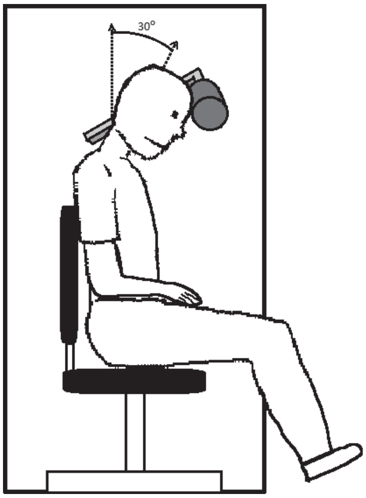

Fig. 2. An illustrative representation of the test set-up for neck muscle strength and endurance during flexion. The participants were positioned in the computerized neck-trainer instrument, restrained to the chair with a strap across the chest. Then, seated with their arms on their lap, they were instructed to press their forehead against the pad as forcefully as possible (strength) or against the load for as long as possible (endurance).

Then, in order to familiarize the subject with the movement the person performed the intended movement against a small load (1–2 kg) a number of times. Finally, to establish maximal muscle strength, 3 maximal voluntary contractions (MVCs) were performed, and the highest value was used for analysis. The participants were instructed to "press their head against the pad as forcefully as possible" in the intended direction. Each contraction lasted approximately 10 s, during which vigorous verbal encouragement was given, and precisely 30 s of rest between each maximal effort contraction was allowed. The same investigator (HK) carried out all MVC trials.

For neck muscle endurance, a 60% MVC was established from the mean of the last 2 MVCs. The subject then continued to keep the arm of the neck-trainer instrument in the same position (15° extension and 30° flexion) against the 60% MVC load for as long as possible. Here, participants were instructed to "keep the load in position with their head until it becomes too uncomfortable".

Statistical analysis

All statistical analyses were performed in STATA14b. First, regression analysis was performed to determine muscle function properties at day 7, 30, 100, 180 and 365. This was necessary because most participants were not able to undergo examination at exactly 1 week/month/etc. after the injury. In addition, it allowed for imputation of missing data from the later examinations due to a considerable proportion of drop-outs. In some individuals who underwent only 2–3 tests, the regression coefficient resulted in negative data for strength (torque) and endurance (seconds) at days 180 and/or 365. Since this is not physically possible, these data-points were corrected to zero.

Between-group data were treated as non-parametric data and differences across groups were calculated (Wilcoxon rank-sum test for time-point specific differences). This approach was chosen after initial analyses (diagnostics plots) showed that data were not normally distributed and that there was a high degree of variability. *Post hoc* analysis was subsequently performed to adjust for multiple comparisons (Dunn's test).

After dichotomization for recovery status, non-parametric *t*-tests (Kruskal–Wallis) were used to investigate differences in neck muscle function between recovered and non-recovered whiplash-exposed individuals. Finally, the data were Bonferroni corrected for multiple comparisons. If not specified otherwise, p-values < 0.05 (after adjustment for multiple comparison) were considered significant.

RESULTS

Subjects

The anthropometrics of the 2 groups are shown in Table I.

Whip vs ankle distortion groups

Neck muscle strength and endurance of Whip and AD at 7, 30, 100, 180 and 365 days after injury are shown in Fig. 3. Overall, the Whip group showed lower CS at all time points in both directions. However, significant difference was not seen at one year for flexion. For CE, Whip also showed lower extensor endurance at all time points; however, this was non-significant during the later sessions. No difference between groups was seen for neck flexor endurance.

Within-group developments

No developments were seen for either group at any time point. For example, CS was similar at day 7 and 365 for Whip (mean 24.40 Nm (standard deviation (SD) 13.70) vs 23.65 (SD 15.2), $p > 0.6$ and mean 19.14 Nm (SD 10.00) vs 20.19 Nm (SD 15.14) $p > 0.3$ for extension and flexion, respectively).

Recovered vs non-recovered

During visits at 6 months and 1 year post-injury, whiplash-exposed patients were examined and asked whether they had returned to pre-injury work routines. This was achieved through the Copenhagen Neck Function Disability Scale, a self-administered

Table I. Anthropometric characteristics of the study populations at first visit

	Whiplash-injured $n = 141$	Ankle-injured $n = 40$
Age, years, mean (SD)	35.6 (10.8)	34.8 (12.0)
Sex, males, %	47.9	47.5
Weight, kg, mean (SD)	75.1 (16.5)	73.7 (13.1)
Heigh, cm, mean (SD)	174.5 (8.9)	174.0 (9.0)
Neck circumference, cm, mean (SD)	35.6 (3.6)	35.5 (3.9)
Education level[a]	3.13 (0.94)	3.35 (0.99)
Baseline global pain (VAS, cm)	2.36 (0.03)	2.17 (0.09)[b]

[a]Ranked numerically by highest education, where 1 = Elementary School; 2 = Secondary School; 3 = Practical Education/Professional School; 4 = University, uncompleted; 5 = University Graduate.
[b]Not significantly different from Whiplash group ($p = 0.18$).

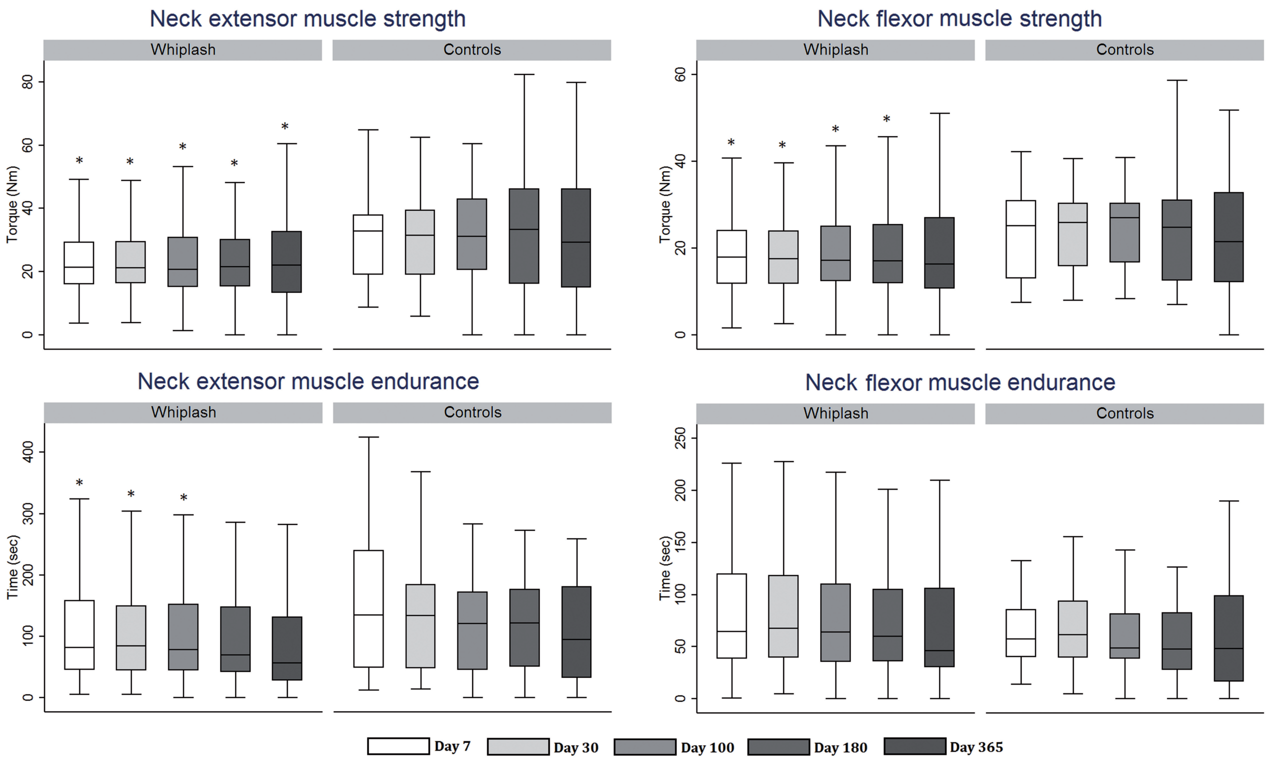

Fig. 3. Neck muscle properties of whiplash-exposed individuals and controls exposed to non-sport ankle distortion, at different time points after injury. Lines represent medians; boxes represent 25% and 50% quartiles; whiskers represent 10% and 90% percentiles. *Significant difference from controls ($p < 0.05$).

questionnaire developed to measure the level of functional disabilities in patients with neck pain (22). If they had reduced working hours or work capacity due to problems from the whiplash injury, they were categorized as non-recovered. Fifteen patients were considered non-recovered at one year after injury. Overall, recovered whiplash-exposed individuals displayed significantly greater CS in both directions at all time points, except day 365 for flexion (see Fig. 4). No significant differences were seen for CE at either time point; however, a notable tendency towards greater extensor endurance was seen for recovered patients.

Compared with the AD group, recovered whiplash individuals exhibited lower CS and CE across all directions and time points; however, the differences only attained statistical significance at day 7 (and day 30 for extensor CS).

Treatment by clinicians

In total, 41% (58 of 141) of whiplash-exposed individuals had received treatment by either a physiotherapist or chiropractor at some time point. At the first visit, individuals who would later seek treatment had a tendency towards lower extensor CS (mean 22.4 Nm (SD 12.0) vs 26.0 Nm (SD 14.9), $p=0.076$) and CE (mean 97.3 s (SD 83.1) vs 127.6 s (SD 115.0), $p=0.053$), and flexor CS (mean 17.6 Nm (SD 9.3) vs 20.4 Nm (SD 10.4), $p=0.061$), than those who did not, and this relationship remained at all time points.

DISCUSSION

The main finding of this study is that CS is compromised in the long-term after whiplash injury. During neck extension, impairments persist even one year post-injury. While a previous investigation on the same population revealed that active CROM and neck pain sensations recover within the first months after injury (17), impairment of neck muscle function is sustained well beyond this period of time. Even though a significant difference between groups was not found for flexion CS at one year ($p=0.29$) and extensor CE at 6 months ($p=0.052$) and 1 year ($p=0.12$), Whip displayed a tendency towards reduced muscle function at these time points, compared with controls. We therefore argue that the lost significant differences are not due to an actual recovery of functioning in Whip. Instead, the high drop-out rates observed in the later test sessions in both groups (25–49% drop-outs) have undoubtedly led to: (*i*) greater uncertainty and variance due to statistical imputation; and (*ii*) smaller sample

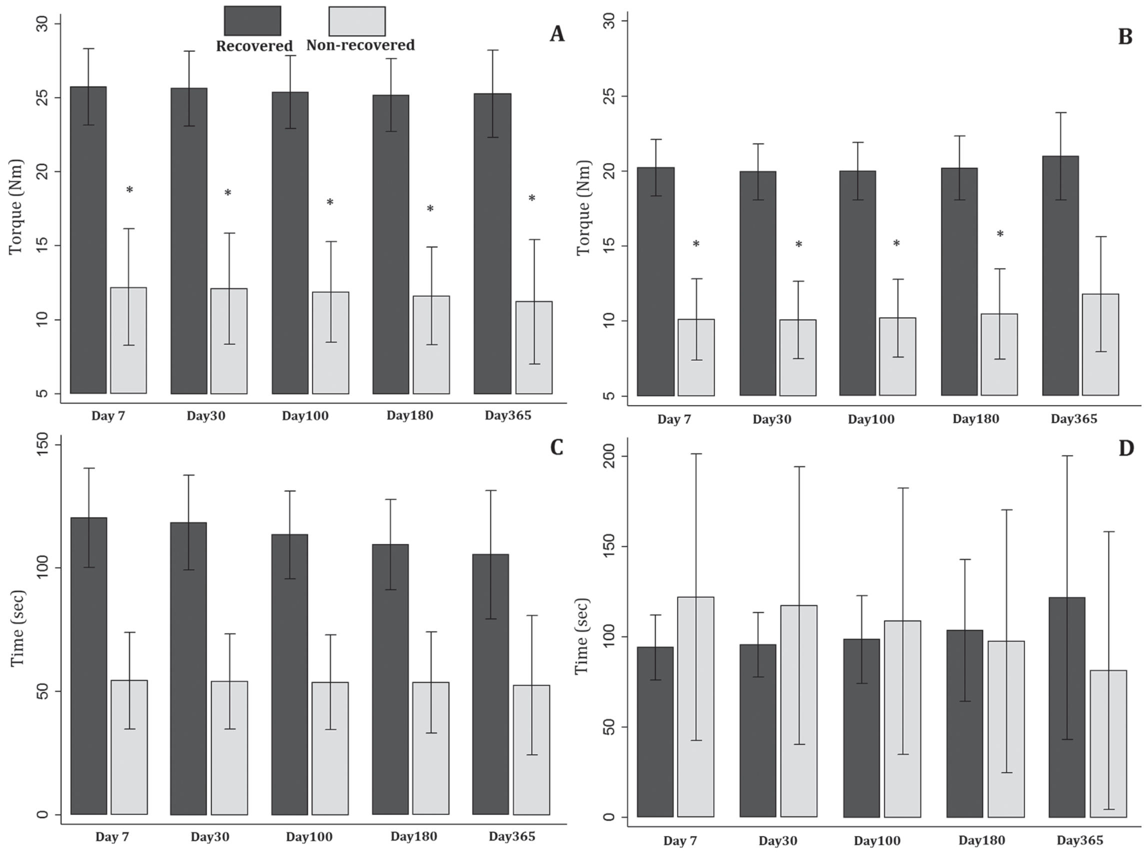

Fig. 4. Neck muscle properties of whiplash subjects considered recovered and non-recovered. (A) Neck extensor muscle strength. (B) Neck flexor muscle strength. (C) Neck extensor muscle endurance. (D) Neck flexor muscle endurance. *Significant difference from recovered subjects ($p<0.05$).

size (due to exclusion of cases where only 1 data point was present), which in turn have led to poor power to detect differences. It is therefore possible that cervical muscle function is affected by a whiplash injury for a time period that extends beyond the scope of this study.

No favourable developments were seen in either muscle parameter at any time point for Whip, despite the fact that the vast majority (~90%) of the whiplash-exposed individuals were considered recovered after one year. Therefore it seems that long-term recuperation of cervical muscle function is complicated after whiplash injuries even for individuals regarded as clinically recovered. However, dichotomization by recovery status did reveal a more pronounced muscular weakness in non-recovery individuals, indicating an important role of CS in rehabilitation after whiplash injuries.

Categorization based on treatment by physiotherapist/chiropractor or not, had no effect on recovery of either CS, CE or self-reported pain levels. This serves as a reminder that chronic WADs are complex disorders that still warrant effective, evidence-based interventions in order to produce specific treatments. Unfortunately, hypersensitivity of the central nervous system following a whiplash trauma may complicate muscular recovery from resistance training. Here factors such as local and widespread hyperalgesia, allodynia, inefficient diffuse noxious inhibitory control activation and enhanced temporal summation of pain, have been suggested as potential mechanisms (20, 23). Also, exercise-induced endogenous analgesia may be "switched off" in this population; meaning that in individuals with whiplash injuries the pain inhibition systems that are activated through exercise are somehow nullified (24).

It is possible that these phenomena influence our results. As maximal muscle contractions may aggravate pain sensations, or simply provoke a fear of pain in patients with WADs, it is likely that the strength insufficiency reported here is related to learned pain avoidance behaviour; a theory supported by others (10, 25). This has caused some authors to propose a rehabilitation approach that combines pain education and cognitive behavioural theory in order to reconceptualize the patient's belief of pain, e.g. reduce the threat of pain (25, 26).

The theory is supported by findings on the alterations of muscle activation patterns in individuals with pain; more specifically (*i*) preferential recruitment of cervical synergists to the painful agonists in combination with increased co-activation of antagonists (27, 28); (*ii*) preferential recruitment of superficial cervical muscle over deep cervical muscles (15); (*iii*) altered corticomotor control even in the absence of nociceptive input; the anticipation of pain suffices (29). As co-activation decreases directional force, and deep cervical muscle function is known to be of importance for general head movement (30) and for cervical flexion in individuals with neck pain (31), these phenomena may contribute to the present deficient cervical muscle function in individuals exposed to whiplash injury.

However, it should be considered if several physiological aspects may also play a part. Despite an initial absence of objective damage to the cervical spine or nerve roots, it is possible that our subjects developed other disorders pernicious to neck functioning. As WADs result in a reorganization of cervical muscle activity (32), concurrent environments of muscular overuse (superficial musculature) and disuse (deep musculature) are likely to be established. Abrupt cessation of muscle activity and mechanical loading is known to have adverse effects on a multitude of neuromuscular characteristics, such as muscle morphology (atrophy, fatty infiltration), strength, fatigue resistance (33), descending neural drive and motor unit behavior (34). Indeed, using magnetic resonance imaging (MRI) neck scans, a rapid and progressive fatty infiltration of the deep cervical musculature (multifidus) has been observed after whiplash injury (35), but not in individuals with non-specific neck pain (36).

Paradoxically, simultaneous local muscular overexertion may be present in superficial neck muscles following a whiplash trauma, due to continuous autonomic activation of low-threshold motor units. This theory is backed by data showing compartmentalized muscle fatigue in the environments of the upper trapezius in individuals with insidious-onset neck pain (37). In this population, local accumulation of nociceptive substances and decreased tissue oxygenation were present due to constant low-intensity muscle activity, and these parameters correlated with the severity of subjective pain sensations; theoretically, these phenomena could also contribute to sustained pain and long-lasting inhibition of neck functioning in individuals with WADs.

Few randomized treatment studies have been performed to evaluate the clinical outcome for these patients. Borchgrevink (38) investigated whether instructions to act as usual (patients continued to engage in their pre-injury activities) in the first 14 days after the accident would elicit benefits, compared with a group that were immobilized with soft neck collar and given time off work in the same period of time. At 6 months follow-up, the act-as-usual group had significantly better outcomes with respect to subjective ratings (VAS) in neck pain and headache, neck stiffness, memory and concentration. Conversely, the Danish Whiplash Study Group did not note any significant differences between groups when employing a similar approach (39). This indicates that encouragement towards continuation of pre-injury neck activity may be a favourable approach for clinicians in patients with whiplash trauma without spine or nerve damage, but that an information-based intervention may not be sufficient to elicit any changes in outcome. A similar scientific investigation that applies quantitative measurements of actual neck muscle activity may elicit further knowledge.

Also, Peterson et al. (40) have compared the effects of 3 different exercise approaches on neck muscle endurance, kinesiophobia, exercise compliance, and patient satisfaction in patients with chronic WADs. After the interventions (neck-specific exercise (NSE), NSE combined with a behavioral approach (NSEB), or prescribed physical activity), the NSE and NSEB groups exhibited greater gains in neck extension endurance, greater reductions in pain after endurance testing, and more satisfaction with treatment ($p \leq 0.03$), compared with individuals in the prescribed physical activity group. Therefore, the application of a neck-specific exercise intervention (with or without a behavioural approach) in clinical practice may produce greater recovery of cervical muscle function, while reducing kinesiophobia, in patients with WADs.

Control group design

When determining an appropriate control group for the whiplash injured, a healthy control group may not be suitable. If designed so, the whiplash group would naturally display significant reductions in neck muscle performance; but the mechanisms behind this actuality would be difficult to elucidate. Could it be due to biomechanical limitations, or to post-traumatic distress, pain presence, or neck-specific pain/neurological disturbance?

Here, a group of sex- and age-matched subjects with acute ankle distortion served as controls. This design was chosen in order to determine whether whiplash injuries represent specific disorders confined to the neck, or whether they are simply manifestations of post-traumatic distress. By recruiting a control group with traumatic injuries distant from the neck, but with similar degree of initial global pain intensity (see Table I), the stress associated with an acute injury would be present in both groups. Hence, we could investigate whether trauma to the neck due to whiplash injury is essential for the development of persistent cervical dysfunction, or if injury and pain *per se* have influence.

Study limitations

A high drop-out rate was observed in both groups in the present study. This probably led to greater uncertainty and variance in the later data points when performing statistical imputation. In addition, a proportion of drop-out participants in each group only underwent a single neck testing session. These participants have been excluded, and this could lead to poor power to detect differences.

It may also be questioned if differential attrition could have biased the results. Although *post-hoc* analysis showed no apparent differences in baseline impairments between the follow-up participants and drop-outs ($p > 0.05$), differential attrition through other factors (not controlled for in this study) cannot be ruled out.

A few participants dropped out due to geographical relocation, others due to sickness/death in the family. However, most did not give any explanation for their discontinuation. For many of these, simple avoidance of the uncomfortable procedure of exerting painful muscles may be the primary reason. Here it could be argued that it was the more impaired individuals from the whiplash-exposed group that abstained from repeating the study procedure. Therefore the difference between the study groups may have been even more pronounced if these individuals had continued, although this remains speculation.

It should be noted, that the concept of recovery following whiplash injury holds different meanings, and the lack of a uniform definition is an inherent problem in this field of study. While return to work is an important measure of recovery, it is not identical with complete, symptomless health recovery. Therefore it is possible that appliance of another index of recovery, such as "presence of pain", might have led to different results.

Furthermore, the presented data have been collected as part of a larger study whose main focus was not muscle function; it is possible that this has caused the study participants to devalue this aspect of the examination. Throughout the experimental trials high within-subject variability was noted in both groups, and compliance with the experimenters' instructions would regularly be modest. Thus, despite vigorous verbal encouragement from the experimenters during muscle testing, it is uncertain if the subjects gave their actual maximal efforts. Also, it should be considered whether the data collected under conditions of cervical pain and tenderness are a demonstration of these individuals' willingness to endure discomfort, and not their actual physiological muscle capacity.

Conclusion

It is evident that impaired cervical functioning after whiplash injuries is widespread and persistent, and its aetiology may be multifactorial across psychophysiological areas. It is likely that WADs, such as pain, neck stiffness and catastrophic thinking after injury, result in a behaviour of muscular inactivity, which, in turn, leads to physiological degeneration and further pain and psychological impacts. Hence, a need for clinically increased focus on neck activity and functionality after whiplash injury is present; future studies should investigate interventions to minimize disuse-induced muscle dysfunction in this population, while confronting the issue of muscular recovery with resistance training.

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