Effects of Whiplash Injury on Median Nerve Mobility: A Comparative Study

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Abstract
Chronic pain following whiplash injury is a challenging condition for healthcare professionals. Clinical signs of changes in neural mobility have been observed in these patients, which may be responsible for symptoms. The present study used ultrasound imaging to evaluate and compare median nerve movement in subjects who have previously had a whiplash associated disorder (WAD) (n=7) with a control group (n=10). Longitudinal and transverse nerve sliding was measured at mid-forearm during neck movement from neutral to contralateral side flexion. Data were analyzed using descriptive and non-parametric statistical methods. Longitudinal nerve movement was reduced by 24% in WAD group compared with control group, where the mean movement was 1.31 (SD=0.49) mm and 1.73 (SD=0.92) mm respectively. Transverse movement was reduced by 66.7% in patient group compared with control group, where the mean movement was -0.06 (SD=0.51) mm and -0.18 (SD=0.54) mm respectively. Overall there was a trend of reduced nerve sliding in whiplash patients but this did not achieve statistical significance. Further research should utilise a larger sample to further evaluate the nature and extent of changes in neural mobility in a patient population.

Keywords: Whiplash; Median nerve; Ultrasound imaging; Nerve movement.

Introduction
Whiplash injuries are an increasing public health problem due to the number of people who go onto to develop chronic pain and disability.¹-³ Most individuals following a whiplash
injury recover in 2-3 months but a significant proportion (14–42%) experiences persistent ongoing pain with 10% reporting constant severe pain. It is this group with persistent symptoms who form the major part of the significant economic costs related to this disorder. Despite the availability of numerous epidemiological publications, the reasons for the persistence of disabling symptoms are not clear. One of the possible reasons could be the lack of sufficient information about the mobility of neural tissues in relation to its surrounding structures.

It has been suggested that the neurovascular bundle may be mechanically compromised by the scalenes and pectoralis minor muscle following trauma to the cervical region resulting in changes to the neural tissue along its peripheral pathway. The viscoelastic properties of nerves allow them to accommodate to changes in limb posture without compromise or strain. Bilecenoglu et al suggest that restriction to normal nerve sliding relative to adjoining tissues/structures could lead to pathophysiological changes in the peripheral nerve. Inflammation of the neural or associated tissue can elevate mechanosensitivity thresholds in the C and Aβ fibers and has been detected during normal physiological movements of the peripheral nerves. In addition to mechanical compromise, peripheral nerves may be damaged as a result of the excessive forces during a hyper-extension-flexion injury associated with WAD. Minor nerve injury and loss of nerve mobility may produce the symptoms of the patients.

Chronic whiplash patients may have neurological symptoms without obvious signs of nerve damage. Neurophysiological investigations, such as EMG and nerve conduction studies, are often normal in these patients which made it difficult to determine the exact pathology. As a consequence, there has been considerable interest in investigating the physical characteristics of nerve by using ultrasonography. Whilst early in vivo studies relied on invasive procedures of needle insertion to detect nerve movement, high resolution ultrasonography and image analysis has enabled researchers to quantify transverse and longitudinal peripheral nerve motion.
Signs of altered nerve movement and changed neural mechanosensitivity have been reported in whiplash patients.\textsuperscript{24} Painful responses have been found in patients having whiplash injury during neural sensitizing manoeuvres; these tests (e.g. ULTT1) assess the mobility of peripheral nerves relative to adjacent tissue.\textsuperscript{11,24,25} A positive finding (pain, muscle spasm, paraesthesia) is indicative of pathophysiology of the peripheral nerve and has been associated with changes in nerve function.\textsuperscript{26} Additionally signs of brachial plexus irritation (positive Tinels sign at the supraclaviclar fossa) and decreased pain threshold to digital pressure have also been reported in WAD patients over sites along the course of the median nerve and cords of brachial plexus.\textsuperscript{11,24,27} It is suggested that altered nerve tension and neural mechanosensitivity may contribute to symptoms in patients having whiplash injury.\textsuperscript{24}

As well as evidence from the peripheral nervous system, evidence exists to implicate the central nervous system (CNS) as a contributor to the perpetuation of symptoms in chronic WAD. Sterling et al\textsuperscript{27} reported a global decrease in mechanical pain thresholds in WAD patients, both locally and remote to the site of injury, indicative of central sensitization. The notion of aberrant central pain processing mechanisms as a contributor to symptoms in chronic WAD is further supported by many other studies.\textsuperscript{28-32} Greening et al\textsuperscript{24} found decreased proximal nerve sliding in both whiplash and non specific arm pain (NSAP) patients during a deep breathing which they associated with reduced first rib excursion. However it is not clear whether this reduced proximal nerve sliding is due to reduced first rib motion or altered environment around the cords of the brachial plexus at thoracic outlet. Due to the sample size and lack of clarity around the sample characteristics it is difficult to derive any meaningful conclusion from this study.

Whilst Dilley et al\textsuperscript{26} reported a trend of reduced proximal nerve sliding (17.9\%) in a NSAP group compared to a control group, the results failed to achieve statistical significance. It may be due to small sample size which might lack the power to detect population effects that are practically important.\textsuperscript{33}

The aim of this study was to evaluate the longitudinal and transverse sliding of the median nerve at the mid forearm
during contra lateral neck side flexion (CNSF) in subjects who have previously experienced a whiplash injury and those who have not.

**Methodology**

**Study design**
A single blinded quasi experimental different subject design was used.

**Sample**
Convenience sample of seven WADII (2 male and 5 female) and ten non WAD subjects (5 male and 5 female) were recruited. Ethical approval with adherence to institutional Research Governance Guidelines was gained with all subjects giving informed consent. Subjects with known neuromusculoskeletal spine conditions, systemic conditions including diabetes and those who had had upper limb/neck surgery or were pregnant were excluded from the study.

**Equipment**
Ultrasound imaging was performed using a Diasus ultrasound system (Dynamic Imaging, Livingston, Scotland, UK) with a 8-16MHz, 26mm linear array transducer as previously described by Dilley et al.²²,²³ Ultrasound imaging has been shown to have fair to excellent reliability (Intraclass correlation coefficient [ICC] = 0.39–0.76) for measurement of transverse sciatic nerve movement and excellent reliability (ICC = 0.75) for analysis of longitudinal movement.³⁴

**Procedure**
A trained musculoskeletal physiotherapist performed all the ultrasound image acquisition. A pilot study was conducted to assess feasibility of procedures prior to main study. Subjects were positioned in supine lying with cervical spine in neutral. The testing arm (the most symptomatic arm in whiplash group and dominant arm in control group) was supported on a Perspex plate with; 30-degrees shoulder abduction, fully extended elbow, supinated forearm²⁴ and the wrist and digits fixed in neutral with external supports²³ (fig. 1).

![Fig. 1: Arm for ultrasound imaging: shoulder abducted 30º, elbow fully extended, forearm supinated, wrist and digits in neutral position.](image-url)
Prior to testing, participants’ necks were moved into CNSF six times whilst maintaining the upper limb position to ensure that stability of nerve motion had occurred. Longitudinal and transverse images of the median nerve at the mid forearm were acquired, first with the head in neutral position then with the neck movement into contralateral lateral flexion (CLF) where this manoeuvre has been shown to tension the median nerve. The nerve motion was initiated by taking cervical spine of the subject into CLF to the first point of resistance (R2) by the research assistant or where symptomatic to first point of pain (P1). Range of CNSF was measured by using a protractor scale on a sheet of white paper under the participants head.

**Longitudinal median nerve imaging**

The sequences of ultrasound images acquired from the mid forearm during CNSF were captured as a cine loop at 10 frames/s using a Diasus ultrasound system (Dynamic Imaging, Livingston, Scotland, UK). The image sequences were analyzed offline using software developed in Matlab (Mathworks, USA) that employs a frame-by-frame cross-correlation algorithm. Resolution of the images was 96 dpi and image size was 596 by 796 pixels.

**Transverse median nerve imaging**

Transverse images were also acquired at mid forearm (fig. 2). The surface of the skin was marked using thin (2 mm wide) strips of tape (Fixamull, Beiersdorf) as used by Greening et al. These strips were applied along long axis of the ventral surface of forearm. Two strips were positioned 10–17 mm apart and could be seen on the ultrasound images as bright lines which cast an acoustic shadow across the image. Images were acquired in neutral position and CLF position. Median nerve location was measured relative to these markers using the tpsDig program (F. James Rohlf, Department of Ecology and Evolution State University of New York). The nerve co-ordinates were measured on frames taken during the rest period at the start and end point of each image sequence. The horizontal and vertical distances of the centre of the nerve from the markers were then determined from the co-ordinates. Change in nerve position was measured by subtracting the values with head in neutral position from those with neck in contralateral side flexed position. The co-ordinates were defined such that
positive values for horizontal movement indicate movement in the radial direction while positive values for the vertical measures indicate dorsal movements.

After taking the measurements, NPT (median nerve bias) was performed on both sides to assess the median nerve involvement and the range of elbow extension was measured by using a Universal Goniometer. The NPT (median nerve bias) has been shown to tension the median nerve and brachial plexus. The test was considered positive if it reproduces symptoms and demonstrates a restriction in the range of elbow or wrist extension. If the symptoms of a patient can be altered by adding or subtracting a distal component of the specific technique, the subsequent response may be due to changes in the corresponding neural system mechanics.

**Data analysis**

Individual and group data were analyzed to quantify the mean longitudinal and transverse motion of the median nerve during CLF.

To assess the reliability of the off line data analysis, inter-rater reliability was performed on the individual data on 3 different occasions and analyzed using an intraclass correlation coefficient (ICC) (3, 1). The mean measure from 3 occasions was subsequently used for the
descriptive data analysis for each group. The range of nerve motion, including means and SD for the WAD and control group was calculated. All data analysis was performed using SPSS version 17.00, where $p < 0.05$.

For inferential data analysis, the non parametric Mann Whitney U test was utilized to explore differences between two groups (control and WAD).

**Results**

The demographic details and clinical findings of NPT (median nerve bias) for both groups are included in table 1. The NPT (median nerve bias) was found positive in two whiplash patients, which may suggest the corresponding nerve tissue involvement.

**Reliability**

The ICC (3, 1) for longitudinal and horizontal movements were 0.96 and 0.92 respectively which shows excellent reliability according to Portney and Watkins$^{43}$ where poor ($r < 0.50$), moderate ($r = 0.50 - 0.75$), good ($0.75 < r > 0.90$), and excellent ($r > 0.90$).

**Longitudinal nerve sliding**

In all subjects the nerve moves proximally during CNSF. The mean nerve excursion was 1.73 mm (SD = 0.92) in control subjects (n=10) and 1.31 mm (SD = 0.49) in whiplash patients (n=7). Although there was a reduction of 24% in nerve movement in the whiplash group compared with control group but there was no significant difference between groups ($P = 0.20$, Mann-Whitney U test).

The Figure 3 shows comparison of longitudinal nerve movement between whiplash and control groups. In control group 50% subject have movement more than 1.51 mm, where as in whiplash group only one subject (outlier in the graph) has more movement than this.

**Transverse nerve sliding**

In 8 of 10 control subjects the median nerve moved toward ulnar side and in remaining 2 subjects it moved toward opposite direction. In control group the
Table 1: Subjects demographic details and clinical findings for upper limb tension test 1 (ULTT1): n, number of subjects; M, Male; F, Female; SD, Standard deviation; +, test positive; -, test negative.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Gender</th>
<th>Mean age (SD) (Years)</th>
<th>Mean height (SD) Cm</th>
<th>Mean Weight (SD) Kg</th>
<th>ULTT1+/−</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whiplash</td>
<td>7</td>
<td>2M,5F</td>
<td>34.71(12.72)</td>
<td>169.79 (7.38)</td>
<td>76 (13.76)</td>
<td>2/5</td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>5M,5F</td>
<td>25.10 (1.45)</td>
<td>171.30 (9.69)</td>
<td>69.80 (15.33)</td>
<td>0/10</td>
</tr>
</tbody>
</table>

mean nerve translation was -0.18 mm (SD = 0.54) and the nerve movement ranged from -0.82 mm in ulna direction to 1.04 mm radially (the negative sign indicates movement in ulna direction) (fig. 4).

In 3 of 7 subjects in whiplash group the median nerve moved radially and in remaining 4 subjects it moved toward opposite direction. In this group the mean nerve translation was -0.06 mm (SD = 0.51) and the nerve movement ranged from -0.59 mm toward ulna direction to 0.74 mm radially. There was no significant difference between two groups (P = 0.63, Mann-Whitney U test), despite a reduction of 66.7% in transverse nerve translation in whiplash group compared with control group.

The angle of neck side flexion was not significantly different between groups (P = 0.38, Mann-Whitney U test) with mean angle 53.6 (SD = 4.7) degrees in control group and 49.6 (SD = 7.61) degrees in whiplash group.

Discussion

The present study found a 24% reduction in longitudinal motion and 66.7% in transverse motion in median nerve at the mid forearm during CLF in WAD compared to a control group. Whilst these results did not achieve statistical significance, the trend for a reduction of neural motion in WAD subjects does
support the findings of Greening et al.\textsuperscript{24} The differences could be accounted for based on WAD subjects characteristics, as those in Greening et al.’s study\textsuperscript{24} had a positive NPT (median nerve bias), where the current study only had 2 subjects with a positive NPT (median nerve bias).

The direction of the transverse movement of the median nerve in the present study was variable with no direction preference noted. Greening et al\textsuperscript{24} however found the median nerve to move radially. This may be due to differences in the anatomy at the measurement sites, where the fascial bands and adjacent parallel orientated tendons of the carpal tunnel may constrain or limit movement to be uniform during.

The present findings showed a trend of reduced proximal nerve sliding in WAD compared with control subjects, suggesting that probably there may be a restriction to median nerve proximally. It is possible that variability between subjects may mask small trends. The results of this study are in agreement with the findings of previous study in patients with NSAP\textsuperscript{26} which also showed a trend of reduced proximal nerve sliding (17.9\%) in patients that failed to achieve statistical significance. It may indicate that median nerve restriction can play a role in producing symptoms of patient.

As WAD II patients were considered for the present study, restriction of the median nerve sliding cannot be ruled out in other sub-groups of whiplash. As the present study did not find significant difference in longitudinal nerve excursion between two groups, therefore alternative mechanisms for symptoms production must be considered. Signs of increased nerve trunk mechanical sensitivity (e.g. allodynia to digital pressure over sites along the median nerve and cords of brachial plexus) have been found in whiplash patients.\textsuperscript{24} Diffuse arm and neck pain may be due to change in nerve environment at the thoracic outlet and carpal tunnel, which may lead to localized inflammation. Inflammation of the nerve or surrounding tissues can lead to increased mechanosensitivity of nerve fibers,\textsuperscript{12, 15-18} responding to small pressure and stretch. This may explain the nerve trunk hyperalgesia and suggest nerve mechanosensitivity rather than frank nerve entrapment may result in painful responses while examining the neurodynamics in whiplash patients, when the longitudinal nerve excursion appears to be within normal range.

Central sensitization has been considered to play a role in symptom production in whiplash patients with neuropathic pain.\textsuperscript{28-32} It depends upon maintenance of ongoing local nociceptive input.\textsuperscript{44,45} In the normal pain state both peripheral nervous system afferent and central nervous system
hyperexcitability occurs. In the presence of central hypersensitivity, either no or minimal and undetectable tissue damage is required to induce pain. This may explain the reason of pain in the absence of evident tissue damage.

There are a number of limitations with the current study. Lack of statistical significance may be due to use of nonparametric test which is less sensitive in picking up significant differences than parametric test and the small sample size which might lack the power to detect population effects that are practically important. Furthermore, the presence of outliers in the patient group (nerve movement = 2.29 mm) for longitudinal movement and control group (nerve movement = 0.24 mm) for transverse movement can markedly influence the results from statistical analysis. The sample size was small which may cause type II error and can decrease the power of statistical analysis. A convenience sample was used instead of random sampling due to constraints of time and resources, which reduces the external validity of the findings. Parametric data analysis methods are more sensitive to detect differences; however the current study did not fulfill the prerequisites for these tests. Imaging should be performed on both sides in both groups in order to find the differences not only between the groups but also within the groups, as done by previous researchers (e.g. Greening et al).

**Conclusion**

Both longitudinal and transverse nerve movements were reduced by 24% and 66.7% respectively in WAD compared to control subjects but no statistically significant difference was found between groups. Future research, using larger sample size and involving other subgroups of WADs, is warranted to further explore the nature and extent of neural tissue motion in a patient population. In addition to this, the central sensitization needs to be explored further to find out its role in symptoms production in this population. This may help the clinicians to understand the underlying pathophysiology of this challenging condition and would enable them to treat it more effectively.

**Acknowledgements**

The author is grateful to Nicola Heneghan for her enriching comments and invaluable support.

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